UNITED STATES DEPARTMENT OF AGRICULTURE

MISCELLANEOUS PUBLICATION No. 280

WASHINGTON, D. C. JANUARY 1938

BIOCLIMATICS

A SCIENCE OF LIFE AND CLIMATE RELATIONS

BY

ANDREW DELMAR HOPKINS

Formerly principal entomologist
Division of Bioclimatics, Bureau of Entomology and
Plant Quarantine, and formerly
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By Andrew Delmar Hopkins

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INTRODUCTION

The purpose of this publication is to give the results of long-continued studies and researches on natural laws and principles of life and climate relations and on systems and methods of their application in agricultural research and practice, with the hope that specialists in different sciences will adopt such of them as may be found applicable in their several lines of work. The subjects treated are restricted largely to the bioclimatic law and allied principles, but at the same time are more or less related to some phase of all the natural sciences. These researches have been based on a life-time study of, and intimate association with, nature, including more than a half century of practical experience in agriculture and more than 40 years as an official entomologist. The official work has involved extensive travel and entomological explorations in West Virginia and in the United States as a whole. It has also included travel through England, France, Germany, and Switzerland on a special entomological mission to Germany in 1892.

In connection with all travel, field work, and farm experience, the broad fundamental features of plant and animal life in general, and of insect life in particular, have been of the deepest interest and have received special consideration. The guiding principle has been to collect and study first-hand facts and evidence rather than to rely on literature. Published data in all of the sciences have been utilized, however, for the acquirement of general knowledge, suggestions, inspiration, and for comparison and verification of evidence, facts, and conclusions, as interpreted by different investigators and authors; but the urge has been to enter and explore a new field and to follow out new lines of inquiry. This has resulted in the development of independent viewpoints along original lines of thought and experience, and has led to interpretations and conclusions different from those of some other writers, while at the same time some disputed conclusions have been fully verified.

The leading authors who have dealt in a comprehensive way with broad questions of biology, climatology, geography, and other natural sciences are so well known as not to need mentioning in this connection; while those who have discussed specific phases of the subjects of natural history and philosophy are so numerous that space is not available to mention more than a few, who are referred to in the text and included in the bibliography.

The author wishes to have it clearly understood that, while the conception and development of the science is original with him, he does not claim originality for any of the facts, evidence, laws, principles, systems, methods, or ideas which may have been recorded by other authors, being content to leave it to the critical reader and to future investigators to recognize that which is new and worthy of acceptance, as in one way or another contributing toward the advancement of the science and practice of agriculture and related human interests.

Some of the references to principles and elements of other sciences may seem crude and elementary to specialists in such sciences, but it is to be kept in mind that each major science and each of its minor divisions and sections contains so many technical terms, complex systems, and special methods peculiar to each, that to some extent they represent different languages familiar only to restricted groups of specialists. Thus in dealing with broad, fundamental laws, principles, and methods of general interest to all specialists, it is necessary that, within a reasonable range of error as to the facts, references to the principles of the other sciences should be elementary, leaving it to the specialist to correct the errors and, if desired, to translate the simple expressions into his technical terms. Although in the many examples and tables given, there may be some errors of computation, statement, and interpretation, they will not affect the attainment of the purpose, which is to outline principles, systems, and methods for the use of specialists, who with a special knowledge of their respective subjects will make adjustments to their individual requirements. The reader should keep in mind that this pioneer work on bioclimatics is intended merely to serve as a foundation for further development along special lines of research and practice, and that, therefore, its faults, either apparent or real, should not be allowed to obscure or detract from the features which may have real merit in rendering the service intended.

In bioclimatics, as in the other sciences, many new words, terms, symbols, and methods are proposed and utilized, but an effort has been made to keep them at a minimum. The illustrations are from preliminary drawings by the author copied by his assistant and finished by expert draftsmen.

The author wishes to acknowledge his appreciation of the helpful interest manifested and facilities offered by J. A. Myers, director of the West Virginia Agricultural Experiment Station, L. O. Howard, former Chief of the Bureau of Entomology, and his successor, C. L. Marlatt. The assistance rendered by immediate associates in the State and Federal service has been in

making and recording observations, assembling data, etc., under the direction and supervision of the writer; that rendered by W. E. Rumsey at the West Virginia Station, is worthy of special mention.

Valuable help also has been rendered by specialists in the Weather Bureau, Bureau of Biological Survey, Bureau of Plant Industry, and the former Office of Farm Management of the Department of Agriculture in supplying or making available recorded data, maps, etc.; and by members of the Geological Survey of the Department of the Interior in furnishing a liberal supply of contour and other maps.

Aid has also been rendered by the committee of bioclimatics of the Department of Agriculture. The members of this committee include J. T. Jardine, Chief of the Office of Experiment Stations, chairman; M. S. Eisenhower and Louis H. Bean of the Office of the Secretary; S. A. Rohwer of the Bureau of Entomology and Plant Quarantine; Wm. J. Humphreys of the Weather Bureau; C. F. Sarle of the Bureau of Agricultural Economics; S. C. Salmon of the Bureau of Plant Industry; and E. N. Munns of the Forest Service. Both the latter and Oran Raber have been particularly helpful during the last 3 years in reviewing the manuscript and making it ready for the printer.

Furthermore, M. A. Murray has rendered indispensable assistance in (1) assembling and card indexing record data from literature and other sources; (2) checking the use of records and computations in tables, examples, charts, and the text; (3) typing the text; and (4) general assistance in the final development of systems and methods of application by test examples.

PRINCIPLES OF BIOCLIMATICS

1. Under the requirements of astronomic law, phenomena of life and climate should be equal under equal astronomic causes along the parallels of latitude around the earth.

2. Under the requirements of bioclimatic law, phenomena of life and climate as modified by terrestrial influences should be equal under equal influences at the same level across the continents along lines which depart from the parallels of latitude at the assumed constant rate of 1° of latitude to 5° of longitude. These lines are called isophanes.

3. Since, however, the influences of the local, regional, and continental causation complex are never equal, departures or variations of the observed effects from the requirements of astronomic and bioclimatic law must occur. Such variations, as determined by bioclimatic methods and expressed in units of time, temperature, or distance, serve (*a*) as measures of the relative intensity of the modifying influences and (*b*) as indices to the interpretation of causes and factors and to the prediction of bioclimatic elements at any given geographic position within the latitude and altitude range of the influence represented by a record position and its variation indices.

4. Under the laws, principles, systems, and methods of bioclimatics the bioclimatic elements of any record position can be analyzed and directly compared, on a strictly coordinate basis, with those of any other position on any continent.

5. The bioclimatic zone and zonal types of a place, area, or local region are the most reliable indices to the species of plants and animals and to the types of agriculture that are best adapted to the local conditions and requirements.

PART 1. LAWS, PRINCIPLES, SYSTEMS, AND METHODS OF APPLICATION

THE SCIENCE OF BIOCLIMATICS; GENERAL OUTLINE

DEFINITIONS

Bioclimatics is a science of relations between life, climate, seasons, and geographic distribution. It deals with fundamental laws, principles, systems, and methods of application in general research and economic practice, and has special reference to the major and minor effects of the major astronomic and terrestrial laws of causation, as represented by the variable phenomena of life, climate, and seasons, relative to the geographic coordinants as expressed, measured, and interpreted in units of time, temperature, and distance.

The science differs from the other branches of biology, climatology, and geography in that it is based on the bioclimatic (and related) laws and principles, and in that it deals more specifically with fundamentals and methods of application relative to the phenomena of seasons, climates, and geographic distribution. It is not, therefore, a branch of any one of the major or minor sciences, but is intended to be supplementary to all in contributing information on fundamentals, and to serve a specific purpose.

NEED AND PURPOSE

The author's studies and research in economic and systematic entomology have led him to believe that in this age of intensive specialization there is need for more information on laws and principles, and for more uniform and coordinate systems and methods of procedure for their interpretation and effective application.

It is the purpose of this work to contribute to these recognized needs and to make the results available to specialists, in order that the results in one branch of science may become available for coordination and comprehensive interpretation in other sciences, especially in agriculture.

NATURAL LAWS

Natural laws, as interpreted and applied in the development of the science of bioclimatics, fall into two major groups; one relating more specifically to major and minor causes, and the other to order and system in major and minor effects. Each of these groups represents many major and minor principles and complex interrelations.

LAWS OF CAUSATION

The major laws of causation are: (*a*) The astronomic laws of the motions of the earth relative to the sun, (*b*) the astroterrestrial laws of combined causes, and (*c*) the terrestrial laws of modifying influences.

LAWS OF EFFECT

The major laws of effect of the major causes, as related to the surface of the earth, are represented in the order and system of (*a*) the ocean and air currents, (*b*) terrestrial seasons, (*c*) climates, (*d*) life, and (*e*) geographic distribution.

The minor laws of effect include (*a*) the astronomic law of equal phenomena along the parallels of latitude around the world, (*b*) the bioclimatic law of equal phenomena along lines of departure from the parallels of latitude across the continents, (*c*) the law of modified terrestrial seasons, (*d*) the law of the climates, and (*e*) the law of the geographic zonation of distinctive seasons, climates, and life, including human culture.

INTERPRETATION OF CAUSES

As interpreted in bioclimatics, the major and minor elements of causation are treated as laws and principles distinct from those of effect. Thus it is considered that the terrestrial seasons, life, climate, geographic distribution, and all other variable bioclimatic phenomena and elements are each controlled not by any specific cause, but by a complex system of causes, representing two major divisions, as follows:

1. Astronomical.—
   a. The sun as the primordial cause of all bioclimatic phenomena.
   b. The motions of the earth in (1) its rotation, as the cause of day and night and the measure of time; and (2) its revolution and the inclination of its axis, as the cause of its seasons and major climates.
2. Terrestrial.—
   c. The major relations between oceans, continents, and islands, in modifying the effects of astronomical causes.
   d. The major and minor physiographic features of the continents and their major regions, in modifying the effects of the major terrestrial causes.
   e. Local topography and physical features, in modifying the continental and regional effects of physiographic causes.
   f. The combination of all major and minor causes, or the *causation complex*, in modifying local effects.

INTERPRETATION OF EFFECTS

In bioclimatics all natural phenomena, including (1) the terrestrial seasons, (2) prevailing ocean and air currents, (3) climate, (4) weather, (5) life, and (6) geographic distribution, together with variability in, and adaptation and evolution of, plants and animals, are interpreted as primarily the effects of major and minor laws of causation.

INTERPRETATION OF FACTORS

The first four of these major effects and the minor effects represented by temperature, humidity, precipitation, and other elements of climate and weather, are commonly referred to as causes of general or specific effects, but in bioclimatics they are all interpreted as major and minor factors, coming between the true cause and the observed effects; and thus serve as keys, or indices, by which a given effect may be traced back through the minor to the major cause, or by which the causation-factor complex may be analyzed and the underlying principles and laws determined.

TIME, TEMPERATURE, AND DISTANCE

In the interpretation of astronomic and terrestrial causes and effects, the three fundamental elements of measurement and expression are:

1. Time, as represented by the rotation and revolution of the earth relative to the position of the sun and stars.
2. Temperature (heat and cold), as governed by the sun and the inclination of the earth's axis and modified by terrestrial causes.
3. Distance, in degrees of latitude, celestial and terrestrial longitude; and altitude above the sea in feet or meters.

PRINCIPLES

The major principles in bioclimatics are:

1. The *requirement constant of natural law*, in which it is assumed that under equal causes there should be equal effects, and that, therefore, the numerical elements by which given effects are distinguished and expressed in units of time, temperature, or distance should be uniform in representing requirement constants of the law.
2. The *modified effects of natural law*, in which it is recognized that effects are never equal across a continent or ocean and that minor causes and factors may be variable, but the range of departure from the requirement constants of a recognized law should be within reasonable limits; and that, in general, the continental average of such departures should agree with the requirements.
3. The *variable and constant*, in which the constant represents the required effect of the law, and the variable is the observed and recorded effect as represented by and interpreted in units of time, temperature, or distance.
4. The *variation of the observed variable from the required constant* is an index to the cause, in which the relative amount and character of the variation is both an index to, and a measure of, the relative intensity of the modifying influences of the causation complex, and thus is the fundamental basis for the interpretation of cause and effect relative to a given bioclimatic phenomenon, subject, or event at a given place.
5. The *causation-factor complex.* It is evident that, as a general principle, regional and local variations from the requirement constants of bioclimatic law are not due to any one cause, or to a few regional or local causes, but to the combination of all, from the major astronomic and terrestrial to the immediate local.

REQUIREMENTS OF ASTRONOMIC LAW

The astronomic law requires that around the earth under equal physiographic conditions the phenomena of seasons, climate, and life should be equal along the parallels of latitude, and that with distance in degrees of latitude poleward and equatorward from a given parallel, or in feet of altitude above or below a given level, the required effects should vary at a constant rate, as measured in units of time or temperature.

Tests of this law have been made in accordance with these principles by the recorded thermal data at representative geographic positions along different parallels of latitude across the continents of the Northern and Southern Hemispheres, and by comparing the records with the requirement thermal constants of the law for the given parallels. The results show that in general (*a*) due to the very unequal physiographic features of the land and the unequal relations between land and water, there are from slight to wide ranges of variations of the records from the requirement constants; (*b*) the variations for the east coast are colder and the west coast are warmer than the requirement for a northern continent and the reverse is true for a southern continent; (*c*) the variation toward the west is much greater than it is toward the east coasts; and (*d*) the average of all variations gives a northwestward trend of the line of equal temperature from that of the parallels.

Thus, since the variations from a law of equal phenomena should be in reasonably close agreement with the average of the records and with the requirement constant, it appeared that the astronomic law of equal phenomena along the parallels of latitude was not sufficiently verified to adopt as a standard basis for application in the interpretation of bioclimatic phenomena, in that (*a*) the range in departures of the records from the requirement constants does not, as a rule, come within reasonable limits, and (*b*) the average of the departures does not agree sufficiently with the requirements.

REQUIREMENTS OF BIOCLIMATIC LAW

The bioclimatic law requires that across the continents under equal physiographic conditions the phenomena of the seasons, climate, and life should be equal at the same level along lines designated as *isophanes*, which depart from the parallels of latitude at the rate of 1° of latitude to 5° of longitude; and that, with distance in degrees of latitude poleward and equatorward from such a line, or in feet of altitude above or below a given level, the required effects should vary at a uniform, constant rate, as measured in units of time or temperature.

Tests of this law by recorded thermal data of representative geographic positions, along representative isophanes and parallels of latitude across the continents of the Northern and Southern Hemispheres, have shown in general (*a*) that the range in variations is less from the isophane than from the latitude requirements, (*b*) that the variations come within a reasonable range, and (*c*) that under ordinary modifying influences the average of the variations across a continent closely agrees with the requirement isophane, and thus serves to verify the law and to justify its adoption as a standard basis for the application of principles in the interpretation of bioclimatic phenomena.

VARIABLE EFFECTS OF MODIFYING CAUSES

With reference to tests of principle 2, it is obvious (*a*) that the major variations from the requirements of the astronomic law of equal phenomena along the parallels of latitude around the earth are due to the major modifying causes represented by the relations between, and the unequal distribution of, the oceans and continents; (*b*) that the major modification of the latitude requirements is represented by the bioclimatic law across the continents; and (*c*) that the minor variations from this requirement are due to modifying causes represented by the major and minor physiographic features of the land and inland waters.

SYSTEMS

Some of the systems that have been conceived and developed in connection with the bioclimatic law and the science of bioclimatics are:

1. A coordinate system of standard unit constant rates of variation in time and temperature with distance in latitude, longitude, and altitude.

2. Standard tables of thermal, time, distance, and zonal constants for general and special subjects, by which the variation of the record variable from its constant for any given record position is determined (appendix).

3. A standard system of the bioclimatic zones and zonal types, by which the zonal and type elements of a given geographic position, local area, or region, may be interpreted from the thermal, time, and biological records of representative record positions. (See classification of bioclimatic zones and zonal types, and the appendix tables of constants.)

4. A standard system of distinctive climates and climatic types, by which the climate and type is interpreted for positions, areas, regions, and continents, by thermal and other climatic elements.

5. A system of application of the variation at a representative record position, and the average of variations at two or more record positions of a local region, in the interpretation of the zones and the zonal, seasonal, climatic, and other types for nonrecord positions within the local or general region represented by the record position or positions.

APPLICATION

Based as it is on astronomic, terrestrial, and physiographic laws and principles of causation, and on the bioclimatic and related laws and principles of effect, the science of bioclimatics has a broad field of application in scientific research and economic practice. It is, in fact, a science of application, in that its laws, principles, systems, and methods are made available to research specialists within any general or specific field of the natural sciences dealing with any phase of the relations between seasons, climates, life, and geographic distribution.

As an example of the application of bioclimatics in a specific economic branch of biology, we shall cite economic entomology, in which some of the bioclimatic problems relating to a given species of insect of economic importance are (1) its natural habitat and distribution; (2) its artificial distribution; (3) its relation to the seasonal, climatic, regional, and local features within the geographic range of its natural and artificial distribution, with special reference to the zone and type centers of greatest abundance and economic importance; (4) dates and periods in its seasonal history, with special reference to average dates of seasonal events in its one or more generations at a given base position and relative to other positions within its range of highest and lowest latitude and altitude limits; (5) relations of events in its seasonal history to favorable and unfavorable elements of the local climatic, physiographic, and other types of influence; (6) relations between its seasonal history and local conditions, and the best time to apply a remedy (or preventive) against an injurious species, or the best way to secure the desired results from a beneficial insect as based on preliminary information on the zonal and zonal type conditions, which will indicate (*a*) the best place and time to look for natural enemies of a newly imported pest, (*b*) when to introduce them, and (*c*) where to locate them to secure the desired results; (7) interpretations from facts and evidence, relative to the natural habitat and distribution of an insect, as to its behavior when introduced into the same or a different bioclimatic environment of another region or continent; and (8) planning and execution of quarantine measures.

Each of these subjects involves bioclimatic problems, which the application of bioclimatic principles will help to solve with the least expenditure of time and money. Indeed, in many cases reliable, preliminary information, at present obtained by expensive procedures and explorations, can be secured by bioclimatic methods with comparatively little or no cost, as will be shown in succeeding sections.

Bioclimatic principles apply in like manner to any other branch of agriculture, and to any branch or type of farm economy or practice in which preliminary or specific information is required on the relations between (*a*) life, climate, seasons, geographic distribution, adaptations, etc., and (*b*) the underlying laws and principles involved.

HISTORY OF THE SCIENCE OF BIOCLIMATICS

CONCEPTION AND DEVELOPMENT

In 1875 in connection with the management of a large farm in Jackson County, W. Va., the author started a farm diary, which included records of temperature, weather, and seasonal events in farm practice such as seeding and harvest dates, first appearance of certain birds and insects, etc. This diary was continued with a few missing years until 1884 and continued at Kanawha Farms until March 1890 when the writer was appointed special agent in entomology at the West Virginia Agricultural Experiment Station with headquarters (for the first 3 months) on Kanawha Farms in Wood County.

These historical references are here made because (1) many of these early diary records of temperature, weather, and seasonal events in farm practice were the first of the kind in that section of the country and have served as valuable data in the development of certain phases of the science of bioclimatics; (2) this experience in agricultural practice laid a foundation for a comprehensive knowledge of the science of agriculture; and (3) from 1890 to 1923 Kanawha Farms has been utilized at intervals, and since 1923 continuously, as a field station for special entomological, phenological, bioclimatic, and agricultural investigations.

While connected with the State Experiment Station special attention was given to the distribution, within the State, of forest-tree species and their insect enemies, and to observations and records of seasonal events of plants and insects; these studies led to the conception and preliminary development in 1895 of a law of "definite normal rate of difference in the periodical phenomena of plants and animals" with differences in latitude and altitude. This line of study was continued at the State Experiment Station until 1902, and from then to 1923 at the Federal Bureau of Entomology in connection with special work on forest insects.

The work on bioclimatic subjects was officially recognized and authorized in 1905 under a special Bureau project on relations of climatic conditions to forest insect life, and subsequently under projects on relations of latitude and altitude to the periodical phenomena of insects (1914) and the bioclimatic law of latitude, longitude, and altitude in its relation to research and practice in entomology and general agriculture.

Work was continued on these projects in connection with the regular forest insect investigations until July 1923, when the writer resigned as chief of the Division of Forest Insects in order to devote all of his time to

research in bioclimatics; and with one assistant, M. A. Murray, he was assigned to the permanent field station at Kanawha Farms near Parkersburg, W. Va.

Considerable progress was made in the development of the law of latitude and altitude (and related principles) before leaving the State Experiment Station in 1902, including the relation of temperature to the latitude and altitude limits of the life zones of West Virginia.

Up to 1902 the field of observation was confined to West Virginia, with the exception of a special mission to Germany in September 1892, for the station and private owners of timber;[1] and three special investigations for the Division of Entomology, United States Department of Agriculture—one to the Pacific Coast States in 1899,[2] one to New England in 1900,[3] and one to the Black Hills of South Dakota in 1901.[4] After 1902 the field for bioclimatic observations was extended to all the States of the Union. In 1918 to secure the maximum yield of grain and to protect the wheat from the hessian fly the results of a comprehensive study of some 40,000 reported winter wheat seeding and harvest dates in the files of the Office of Farm Management of the Department were published as a war contribution toward an increased food supply under the title of "Periodical Events and Natural Law as Guides to Agricultural Research and Practice." In this contribution the first comprehensive published account was given of the bioclimatic law and its principles, systems, and methods of application.

The subsequent years have been devoted to intensive study and research and to the further development of the law and science. The data on which original research has been based, in addition to the original observations and records by the writer and his associates, have been the published biologic, phenologic, climatic, and other records as gathered from standard books and special contributions relative to all of the natural sciences. These data have been studied with special reference to natural laws and to the relation between climate and the geographic distribution of organisms.

HISTORICAL LITERATURE

In connection with the conception and present development of the bioclimatic law, some of the early literature on phenology with regard to certain principles has been helpful, especially in determining the rates of variation in dates of periodic events of plants with distance in degrees of latitude and longitude, and in feet or meters of altitude.

In 1817 Jacob Bigelow, Rumford professor and lecturer on materia medica and botany in Harvard University, concluded from studies of the dates of the flowering of certain plants (principally peach) at places between Montreal, Canada, and Fort Clairborne, in Alabama Territory, that "it may be inferred that the difference of season between the northern and southern extremities of the country is not less than two months and a half."[5]

It seems that the observations and conclusions by Bigelow served as a foundation for subsequent phenological observations and literature in Europe, and for much additional information on the relation of time to degrees and meters of distance.

In 1830 Schübler found that the rate of difference in dates of certain seasonal events between Parma, Italy, and Greifswald, Prussia, was 4 days for about 1° of latitude and about 100 meters (328 feet) of altitude. In 1866 Fritsch concluded that the rate for latitude was 3 days to 1°. In 1846 Quetelet recognized a variation in dates with distance in longitude, but it appears that the rate was not suggested until 1866, when Fritsch concluded that it was about 0.4 to 0.7 (average 0.55) of a day earlier westward for each degree of longitude. In 1893 Ihne concluded that the average difference due to longitude in Europe was about 0.9 of a day for 1°.

Previous to 1900 the author arrived at the independent conclusion that for West Virginia the rate in time to distance in latitude and altitude was about 4 days to 1° of latitude and 400 feet of altitude; and about 1905 (1915, Hopkins) he concluded, from extensive phenological and other data from representative places in North America, that for spring events there was a countrywide average rate of 4 days earlier westward to 5° of longitude.

These rates of 4 days in time to 1° of latitude, 5° of longitude, and 400 feet of altitude, as applied to the Continent of North America, were later adopted as the standard coordinate unit constant rates to represent the average requirements of the bioclimatic law.

COMPARISON OF RATES IN TIME TO DISTANCE

The rates in time to distance in latitude, longitude, and altitude, as proposed by different authors, are as follows:

Geographic coordinants, distance, and time

Author and date	Latitude, 1°	Longitude		Altitude	
		1°	5°	100 meters	400 feet
	Days	*Days*	*Days*	*Days*	*Days*
Schübler, 1830	4			4.00	4.87
Fritsch, 1865–66	3	0.55	2.75	3.05	3.73
Ihne, 1893	4	.9	4.50		
Hopkins, 1897–1915	4	.8	4.00	3.28	4.00

Thus, while time and distance elements of a principle were recognized by Schübler, Quetelet, Fritsch, Ihne, and others, this principle was not developed into a coordinate system or law. Moreover, the rates for longitude and altitude recognized by the writer differ from the earlier ones; and the development of the principle into a coordinate system of unit constant rates in time, temperature, and distance as a bioclimatic law, was based on original research, as was also the development of the law to its present status.

CONCEPTION OF THE BIOCLIMATIC LAW

From results of special investigations made in 1895–97, a law of latitude and altitude was conceived relative to the range and limits of life zones, events in the seasonal history of the hessian fly, the periodical cicada, and seeding and harvest dates for winter wheat in West Virginia in which the range and limits of the life zones were based on ranges in average summer temperature,[6] and the dates to seed winter wheat to avoid damage by the hessian fly were based on the average rate of 4 days to 1° of latitude and 400 feet of altitude; in this way a calendar of seeding dates was computed to apply to any geographic position in the State (1900 Hopkins).

[1] W. Va. Agr. Expt. Sta. Bull. 56. 1899.
[2] U. S. Dept. Agr., Div. Ent. Bull. 21 (n. s.), 1899.
[3] U. S. Dept. Agr., Div. Ent. Bull. 28 (n. s.), 1901.
[4] U. S. Dept. Agr., Div. Ent. Bull. 32 (n. s.), 1902.
[5] If the distance is about 18° of latitude and the time about 75 days, the rate would be about 4 days to 1°.

[6] U. S. Dept. Agr., Div. Ent. Bull. 17 (n. s.), pp. 48, 49; 1898.

In 1920 a table of coordinate unit constant rates to represent the requirements of the bioclimatic law was given as follows:

Coordinants of the bioclimatic law

Geographic coordinants	Geographic unit coordinants	Time coordinants	Distance coordinants
		Days	*Feet*
Latitude	1°	4	400
Altitude	400 feet	4	400
Longitude	5°	4	400

Although a unit constant rate for temperature is not here included, the question of the relation of temperature to time and distance had been under consideration from about 1895, when efforts were made to find a unit constant rate which would coordinate with the time and distance units. In April 1920 this was published in a table, which is quoted below with revised headings:

Geographic, time, and thermal coordinants of the bioclimatic law

A. FOR LATITUDE, LONGITUDE, AND ALTITUDE

	Unit constant coordinates				
				Modifying	
	(*a*) Geographic	(*b*) Time	(*c*) Thermal	(*d*) Thermal	(*e*) Time
		Days	°*F.*	°*F.*	*Days*
1. Latitude	1°	4	1	0.25	1
2. Longitude	5°	4	1	.25	1
3. Altitude	400 feet	4	1	.25	1

B. FOR ISOPHANE AND ALTITUDE

	Unit constant coordinates				
				Modifying	
	(*a*) Geographic	(*b*) Time	(*c*) Thermal	(*d*) Thermal	(*e*) Time
		Days	°*F.*	°*F.*	*Days*
1+2. Isophane	1°	4	1	0.25	1
3. Altitude	400 feet	4	1	.25	1

In A above, the thermal unit of 1° F. is for average rate of the annual mean for a long period of time and all latitudes; and while this served the general purpose of a coordinate unit in expressing the thermal requirements of the law, to conform more nearly with relative effects it was necessary to introduce a modified unit of about 0.25° F. per unit of 1° of higher latitude above the intercontinental base. In other words, above about north latitude 39° the annual temperature has an accelerating effect on life activities, and to provide for this it was first proposed to reduce the 1° rate by 0.25° F. for each 1° of latitude, but in the revised rates, as given under appendix table 3, this is provided for by the schedule of modified rates for given ranges in isophanes. The given time unit (*e*) of 1 day is merely the equivalent in time to the modifying thermal unit.

In B above, for isophane, longitude, and altitude, the isophane includes the latitude (1) and longitude (2) elements of section A, because the departure of the isophane from a given parallel of latitude and meridian of longitude is at the rate of 5° of longitude to 1° of latitude. Thus in the application of the isophane principle the longitude rate is not utilized as a separate unit.

Studies and applications of the modifying thermal units led, in September 1920 to the development of a preliminary table of modified thermal constants, which, with a number of subsequent revisions, resulted in appendix table 3, which is now the standard for application of the thermal unit in bioclimatic research. It will be noted in the explanation of this table that the schedule of modified rates gives an average for the annual mean (*a*) from the equatorial (0) to the polar isophane (90) of 1.05+° F. to 1° of latitude or isophane, but that the gradation in modified rates ranges from 0.42° F. (for isophanes 0 to 1) to 1.375° F. (for isophanes 70 to 90).

The history of the conception and development of unit constant rates and tables of requirement constants of the bioclimatic law and other laws has been by far the most important feature of the development of the science because the results represent the basic principles of the system of requirement constants. In fact this system provides the fundamental keys, not only to the interpretation of the natural laws that they represent, but also to the interpretation of bioclimatic and seasonal phenomena in general, and the bioclimatic zone in particular.

UNIT CONSTANT RATES OF THE BIOCLIMATIC LAW AS DEVELOPED TO DATE

The standard unit constant rates as developed to date both in unmodified averages for the isophanes from the Equator to the poles and as modified for special ranges in isophanes are given in schedules of rates under each of the tables of thermal, time, and distance constants in the appendix.

APPENDIX SCHEDULES

The schedules given in the appendix are elements of the system of constants but are applied in a different way from those of the tables. Schedule 1, gives low temperature types; schedule 2, monthly or daily thermal mean indices for the beginning of the seasons; schedule 3, relative humidity types in percentage, and precipitation types in inches; schedule 4, month and year dates for a normal year by the 12-month calendar; and schedule 5, sums of 12-hour units and percentage of daytime.

In all thermal and time tables of constants, distance in degrees of latitude is represented by the sea-level isophanes or latitudes, and in all tables of altitude constants it is represented by feet above sea level. Thus in thermal table 2 the altitude equivalents to the poles above the sea-level isophanes equatorward are given for each one-quarter degree isophane at the unit constant rate of 100 feet, beginning at sea level on isophane 90 and ending with 36,000 feet above sea level on the equatorial isophane. (See tables 2, 10, and 11 and fig. 55.)

One of the significant features of the rates in time is in their general agreement with the standard 4-day unit constant-rate requirement of the bioclimatic law, in that the rate requirement of astronomic law of the seasons for movement in time between the tropical circles is an average of 3.89+ days to 1° of latitude, and for the astroterrestrial law the average rate of movement in time between latitude 27 and 66.46° is 4.62+ days to 1°.

ZONAL AND ZONAL TYPE CONSTANTS

The bioclimatic zones and their various zonal types, as frequently utilized in part 1, and as classified and

described in part 2, represent a basic law; and the tables of bioclimatic constants, with their coordinate zonal constants for the sea-level isophanes, represent the basic system of application.

The frequent references to, and application of, the bioclimatic zones and types as characterized by ranges in temperature, time, and distance, and applied in test examples, render it important that this subject (as discussed in part 2) should be thoroughly studied and understood.

TABLES OF COORDINATE CONSTANTS

In all tables of requirement constants of the bioclimatic law, unless otherwise specified, the given time, thermal, or distance units and schedule of zonal constants are coordinants of the corresponding isophanes.

The development of the elements and systems of unit constant rates of variation in time and temperature with units of distance in latitude, longitude, and altitude, and of the systems of tables of bioclimatic constants and the bioclimatic zones, has been a process of gradual evolution, in which the inception and development of one system have led to the conception of another. It has been like the evolution of a complicated mechanical invention, in which, guided only by broad fundamental principles, all of the elements have to be worked out and coordinated into a complete machine that will function. There is, however, a difference between the invention of a principle or system of natural phenomena and the invention of a complicated piece of machinery, in that all of the elements of nature are more or less variable and often exceedingly so. Therefore, the precision required in the elements of a machine, or in mathematical formulae, is not only impossible but unnecessary in dealing with the evidence and facts in nature. Thus, while *the bioclimatic constant is a theoretical element of precision in representing an invariable requirement of natural law, its purpose is to serve as a reliable basis for measuring variations from it.*

THE BIOCLIMATIC ISOPHANE

The concept and development of the isophane principle, as representing a requirement constant of the bioclimatic law for equal phenomena along lines of departure from the parallels of latitude across the continents of the world were of fundamental importance in the development of the science of bioclimatics.

ORIGIN OF THE TERM ISOPHANE

The term *isophane* was adapted from Hoffmann (1881–82), who was the first to propose it to represent equal phenological phases. It was applied by him to designate the colimits of his phenological zones as characterized by ranges in dates of phenological events of certain plants.

Hoffmann's term was evidently intended to supplement the *isanthesic lines* suggested by Quetelet (1846) for phenological charts or maps to represent lines of equal dates of full bloom. Gunther (1895), in reference to Hoffmann's maps, stated that the isophanes should be called *homophanes*. Later the term *isophene* was adopted by Adames and Clark (1916) to represent a line of equal flowering dates across the British Isles.

As applied by Hoffmann, Ihne, Adames, Clark, and others, the lines of equal phases represented equal dates between phenological zones or districts and, therefore, might properly have been termed *isochrones*, because they represent in fact lines of equal dates in the order of time.

The bioclimatic isophane, as adopted in the science of bioclimatics to represent a line of equal phenomena, is quite a different concept in that it represents a requirement constant of natural law in either time, temperature, or distance, or a combination of these elements. It differs also in principle and application in that (1) it is a geographic coordinate with latitude, longitude, and altitude in the designation of geographic positions; (2) it serves as a uniform basic line of reference for computing requirement constants of the bioclimatic law in terms of time, temperature, or distance for geographic positions on any continental area of the world, and for application in (*a*) the interpretation of distinctive climates and climatic types, seasons and season types, and bioclimatic zones and zonal types; (*b*) the interpretation of the geographic range and limits of distinctive climates, seasons, and zones, and their many major and minor types for local and general regions, so far as basic records of time, thermal, or distance elements are available for representative positions; (*c*) the determination of variations of the recorded variable from its requirement constant; and (*d*) the measurement in terms of time, temperature, or distance in degrees of latitude or feet of altitude, the relative intensity of the complex influences which cause the variation from the requirements of natural laws.

Thus the principle of the bioclimatic isophane and its systems of requirement constants meet, at least in part, the obstructive criticisms of Gunther, Drude, Ihne, and others of the moves by Angot, Fritsch, Hoffmann, and other writers towards "the Utopia that a definite numerical relation will be established" between phenological dates and the geographic coordinates with special reference to altitude. It meets this criticism in that it provides a simple mathematical principle and method of expressing numerical relations between geographic coordinates and the elements of time and temperature, not only in phenological but also in bioclimatic phenomena in general.

THE PARALLELS OF LATITUDE

From early history the parallels of latitude have been recognized as lines of equal climatic, seasonal, and biologic phenomena. This led to many erroneous conclusions and interpretations as to the actual distribution of terrestrial seasons, climates, and life, especially in the conception of the major zones as uniform belts around the world over land and water, sharply separated and defined on maps by the tropical and arctic circles.

Since the parallels of latitude represent unmodified astronomic requirement constants, they may be interpreted as *astronomic isophanes*, as distinguished from the *bioclimatic isophanes*, because the same system of unit constant rates and tables of constants computed from a base position for the isophanes serve the same purpose as though computed for the parallels.

It is found, however, that the bioclimatic law, with its isophane principle, involves terrestrial modification of astronomic law, and thus more nearly represents the observed facts of the geography of bioclimatic phenomena relative to the continental areas of the world. It is for many reasons preferable in bioclimatics to adopt the isophane as the unit of reference instead of the parallel of latitude. (See test examples and comparisons of

variations from isophane and latitude constants in the following sections.) The principal objection is the requirement of *isophane maps*. This is not a serious matter, however, because any outline or detail map is easily converted into an isophanal map by drawing parallel isophanes on it at the rate of 1° of latitude to 5° of longitude from the one-hundredth on any numerical meridian ending in units of 0 or 5, and the same ratio for fractions of a degree. Moreover, a table of isophane constants may be utilized as latitude constants in the same way and for the same purpose, because the numerical designations are the same.

HISTORY OF PHENOLOGIC AND BIOCLIMATIC BASE POSITIONS

Quetelet (1846) adopted Brussels, Belgium, and Hoffmann (1881) adopted Giessen, Germany, as a base for the comparison of dates of the same phenological events at other places in the country, but this principle, together with the altitude principle, was severely criticized by Drude, Gunther, and others; and this criticism apparently was the cause of the subsequent quite general neglect of the principle of the phenological *base position*, which in bioclimatics is necessary because it serves as a single basis of reference. The unwarranted criticism by the then-recognized authorities evidently served to prevent, or at least retard, the development of two of the fundamental principles of comparative studies of phenological data: (1) That of the base position and (2) that of variation in dates with distance in altitude, latitude, and longitude.

THE BIOCLIMATIC BASE

In bioclimatics the base is a local position or area from the records of which time, thermal, or other bioclimatic constants are computed for the isophanes of any sized region or area. Thus the geographic range of its application to the subject involved may be variously designated as local, regional, continental, or intercontinental. In any case, it represents the principle of a uniform basis for comparing recorded bioclimatic data with their constants within a specified range in isophanes.

It does not imply that a selected base position is a *normal* or average for a continent or the world, because such a position does not exist for the many hundreds of elements of climate, life, seasons, etc. Indeed, *it need not be the most representative position as to its local area or region.* The essential requirement is that it should have a representative series of records, especially of meteorological data, and *should be selected with a reasonable assurance that records will be kept there for a long time in the future.* No matter where a base is located, it is in general representative of the major elements of cause and effect of its local area, region, or specific geographic position. It thus represents, within a reasonable range of error and modification, a bioclimatic center, so that all bioclimatic constants computed from its records are its coordinates, and all records at any position within or outside of the range of its local area are relative to it through their variations from the requirement constants of the natural law involved.

Thus, any specific or average variation of a time or thermal record from a position constant is relative to the requirement of the law for the given position. In a like manner, the determined or interpreted bioclimatic types represented by any one position are relative to the base position, no matter how widely the types of any given position may depart from the requirement constant.

It is to be kept in mind that, if the same standard unit constant rates in time or temperature are utilized to compute constants from any two or more base positions, the difference between any two constants (for the same subject) would be the difference between the base record of one and the constant of the other. For example, if the average record year-date for winter wheat harvest at the intercontinental base position, Kanawha Farms, on isophane 43 at 600 feet is 174, the constant for a position at the same level on isophane 47 would be [$47°-43°=4°\times4$ (days to 1°)=16 days+174] year-date 190. Now if this position on isophane 47 is adopted as a local or continental base with the record average year-date 180, it would be 10 days earlier than its intercontinental constant; or if the record year-date is 200, it would be 10 days later. Thus all constants computed from the records at each of the two base positions would have a difference throughout of 10 days earlier or later as the case might be; so that the constants computed from a local or continental base could be converted into intercontinental constants, or vice versa, by subtracting or adding the difference in days between their constants.

In this way the difference between Quetelet's Brussels, or Hoffmann's Giessen, as a local or regional base, and Kanawha Farms as the intercontinental base, is simply the difference between the local record and the intercontinental constant for the local base position. Thus all results of comparison of records with the intercontinental or local constants for any number of positions would be coordinate and directly comparable in indicating, by the difference in variations, the intensity of the continental influences relative to that at the intercontinental base, or of the local influences relative to that at the local base (see pp. 57–59).

Thus the intercontinental base, through its system of time, thermal, and distance requirement constants of bioclimatic and related laws, represents the fundamental principle and system in the application of bioclimatics to research and practice.

MERITS OF THE SYSTEM

The special merit of the system, principles, and methods by which bioclimatics is applied in research in any biologic, climatic, geographic, or other subject to which they relate, is the uniformity in methods of procedure and in comparison of results on a coordinate basis. Thus the application of the system of constants to any study on the bioclimatic features of a given problem, carried on at a given geographic position, will be in accordance with such broad, uniform, basic principles, that the results will be directly comparable with those attained by the same system at any other position in the world, and so facilitate a comprehensive study of a given subject within its geographic range.

It is important, therefore, to keep in mind (1) that bioclimatics is a science of averages (expressed in constant and variable quantities) and relations, and of variations from requirement constants of astronomic, bioclimatic, and related laws of cause or effect; and (2) that it is a science of application of fundamental laws and principles in accordance with coordinate systems and methods of procedure.

HISTORY OF THE BIOCLIMATIC ZONE

The conception and development of the law of the bioclimatic zone, or the geographic zonation of life and

climate, as characterized by elements of temperature, time, and distance, is based on, and is intended to include with modifications, the long established ideas of geographic distribution, as variously designated by the terms climatic and life zones, regions, provinces. etc.

Although the literature on this subject is far too extensive to discuss, the writer wishes to acknowledge in this connection the work of C. Hart Merriam (1894–98) on the life zones of the United States and North America, because it served as the real inspiration for the studies and research which led to the concept of a science of bioclimatics as here represented.

While the development of the bioclimatic zone has been along different lines, to include life, climate, and the seasons, the basic principle has been that of so-called control by relative heat and cold as represented, not "by the sum of the daily temperature above a given zero", but by *the average annual mean and that of the means of the warmest and coldest months.* There is also a difference in designation, in that, instead of names, a system of standard numerals is adopted for the bioclimatic zones (see classification of bioclimatic and season zones, part 2) and in that the classification includes the continental areas of the world. The special difference which is of fundamental importance in interpretations and application is the principle of the *zonal type*, representing distinctive modifications of the *minor zones*, as characterized by given ranges in the average annual mean temperature. There is another important difference of application in that primarily the zone or type is interpreted, or determined, (1) for the specific geographic record position, (2) for nonrecord positions, (3) for local areas, (4) for the general region or country, (5) for the continent, and (6) for the world.

The interpreted zones and types for specific local positions, and those of areas, regions, countries, and continents serve as indices to the preparation of zonal maps, but such maps can give only a general idea and picture of the areas or regions in which given zones and types may be expected to prevail and thus are of minor importance as guides to the zones, types, and other bioclimatic elements of a place.

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APPLIED BIOCLIMATICS; GENERAL PRINCIPLES' SYSTEMS, AND METHODS OF PROCEDURE

This and succeeding sections deal with principles, systems, and methods of application of the science of bioclimatics.

BIOCLIMATIC ISOPHANES AND ISOPHANAL MAPS

Bioclimatic isophanes are drawn on a map of a country, continent, or of the world at the rate of 1° of latitude to 5° of longitude, as shown in figures 1 to 6 and 9 to 11. They are numbered to correspond with the parallels of latitude intersected by them on the one hundredth meridian of longitude west and east of Greenwich and thus apply alike to the continents of the Western and Eastern Hemispheres.

In figures 1 to 5 the isophanes are given at intervals of 10° of latitude on the meridians of longitude and at the rate of 10° of latitude to 50° of longitude, or one to five, in continuous lines across the land, and broken lines across the water, which show that, as expressions of the requirement constants of bioclimatic law they apply only to the land, except so far as the reverse southwest trend across the oceans may represent similar marine phenomena.

In figure 1 the base isophane 43 west, and in figure 3 its equivalent east, is added for the Northern Hemisphere; and in figures 2 and 4 for the Southern Hemisphere.

The one hundredth pheno-meridian (*p-m*) west is shown in figure 1; the fiftieth west, in figure 2; the one hundredth east, in figure 3; the fortieth east, in figure 4; the one hundred and fiftieth east, in figure 5; and the twentieth west, in figure 6, merely to indicate a general trend of the poleward and equatorward movements of seasonal phenomena relative to the isophanes.

In the map of the world (Mercator's projection) (fig. 6) the isophanes are shown in straight lines at intervals of 20° of latitude to 100° of longitude as unbroken lines across the land and broken lines across the oceans. It will be noted that, while the numerical designations are the same on the one hundredth meridians east or west, there is a difference of 40° on pheno-meridian 20w between those for the Eastern and Western Hemispheres. This is due to the southeast trend of the western and northwest trend of the eastern isophanes of the same numerical designation from the one hundredth meridians (west and east) to the Atlantic coast. Thus, if the isophanes of the same number were connected across the Atlantic Ocean, isophane 40, e. g., would appear as a line whose southwestward trend across the Atlantic corresponds in general with that of the mean annual 40° F. isotherm. There is also a general agreement in the trend of the 40° isotherm and the fortieth isophane across North America and Eurasia.

Thus the parallel isophanes in their northwest-southeast departure from the parallels of latitude serve to represent the requirements of bioclimatic law for equal phenomena across the continents alone in the same way that the parallels of latitude represent the requirements of astronomic law for equal phenomena across both the continents and oceans.

The isophane serves also as a geographic coordinate with those of latitude, longitude, and altitude, in that a geographic position on a continental area is designated and located by its *isophane*, *longitude*, and *altitude* in the same way that it is by latitude, longitude, and altitude, because distance in isophanes is always equivalent to distance in degrees of latitude.

Thus for a position on the one hundredth meridian the numerical designations of the isophane and parallel of latitude are the same, but, owing to the departure of the isophanes from the parallel at the given rate, the numerical designations of the isophane and latitude differ for positions on any other meridian, relative to its distance east or west of the one hundredth.

The west and east isophanes correspond in principle and application relative to any geographic position, in that a given isophane (as, e. g., 43 crossing the forty-third parallel of latitude on the one hundredth meridian east or west of Greenwich) has the same relation to the parallels across Eurasia as it does to those across North America, but it is limited in its northwest-southeast trend to the western and eastern coasts of each continental or insular area; so that the length of a given isophane is proportional to the width of the area of land crossed by it.

It will be seen that isophane 43 across Eurasia from coast to coast extends from about longitude 140 E. on the eastern coast of Japan to about 5 E. on the western coast of Norway, over 135° of longitude. Isophane 43 across North America extends from about longitude 75 W. to 124° W., over 49°; isophane 43 across Africa extends from about longitude 15 E. to 32 E., over 17°; and isophane 43 across South America extends from longitude 67 W. to 76 W., over but 9° of longitude.

The departures of the isophanes from their corresponding parallels of latitude vary with the distance in longitude; for example, isophane 43 across Eurasia is 8° of latitude below parallel 43 in Japan and 19° above it in Norway; while in North America it is only 5° south of latitude 43 on the eastern coast and 5° north on the western coast.

While this system of continental isophanes represents the requirements of the bioclimatic law, as related to any sea level or any common level across the terrestrial areas alone, and while the parallels of latitude represent equal phenomena and apply to both the land and water, it is found that lines of equal effect in the phenomena of life and climate correspond in their trend with the isophanes rather than with the parallels of latitude. This is plainly indicated by (*a*) the sea-level isotherms of average temperature (see isotherm 40° F. in fig. 6 and 30° F. in fig. 23); (*b*) the sea-level limit lines of the geographic distribution of major climatic zones as characterized by temperature; and (*c*) the sea-level limit lines of terrestrial life and climate as represented by the equatorward and poleward limits of major zone II. (See part 2, figs. 36 and 37.)

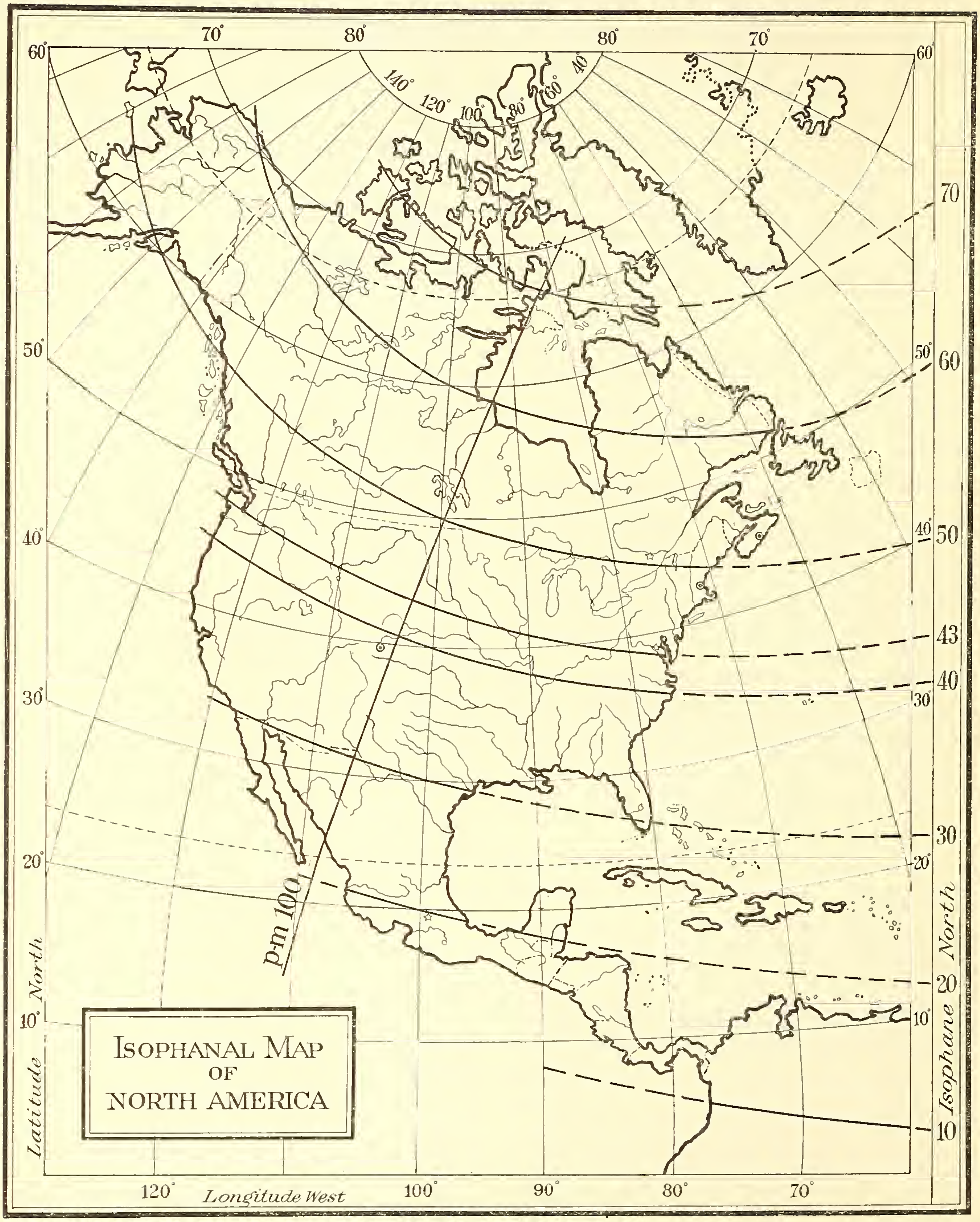

Figure 1.—Isophanal map of North America.

Figure 2.—Isophanal map of South America.

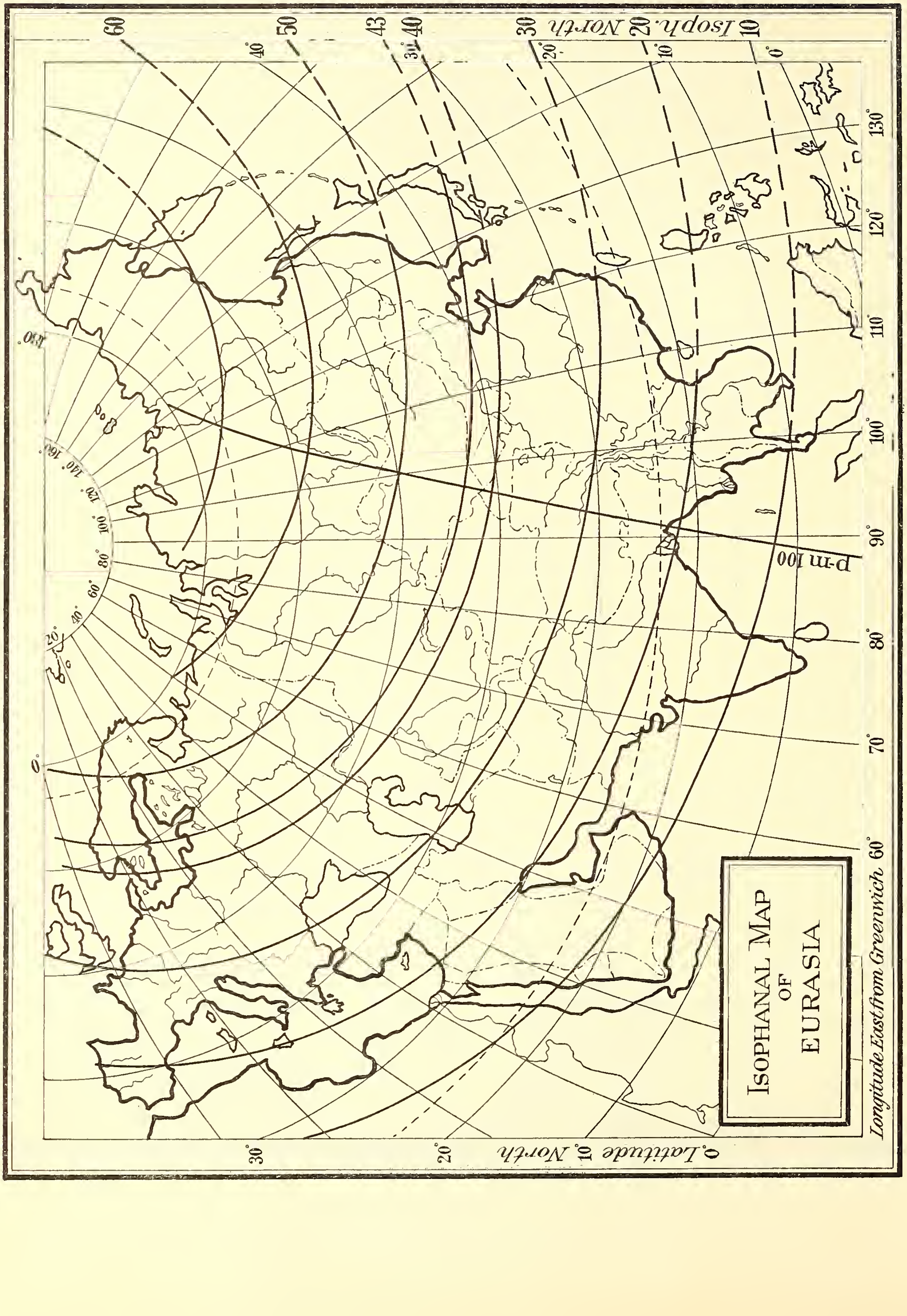

FIGURE 3.—Isophanal map of Eurasia.

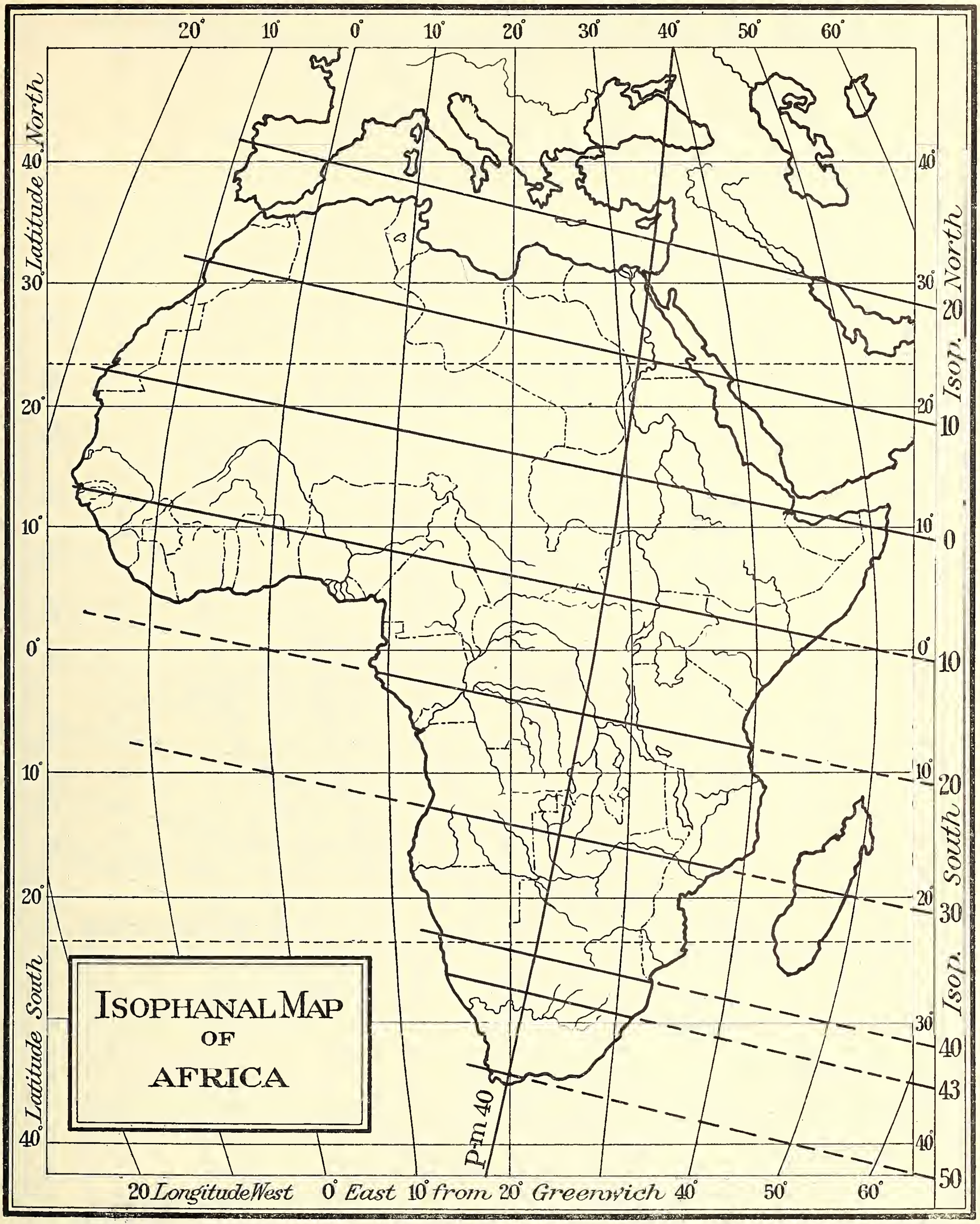

FIGURE 4.—Isophanal map of Africa.

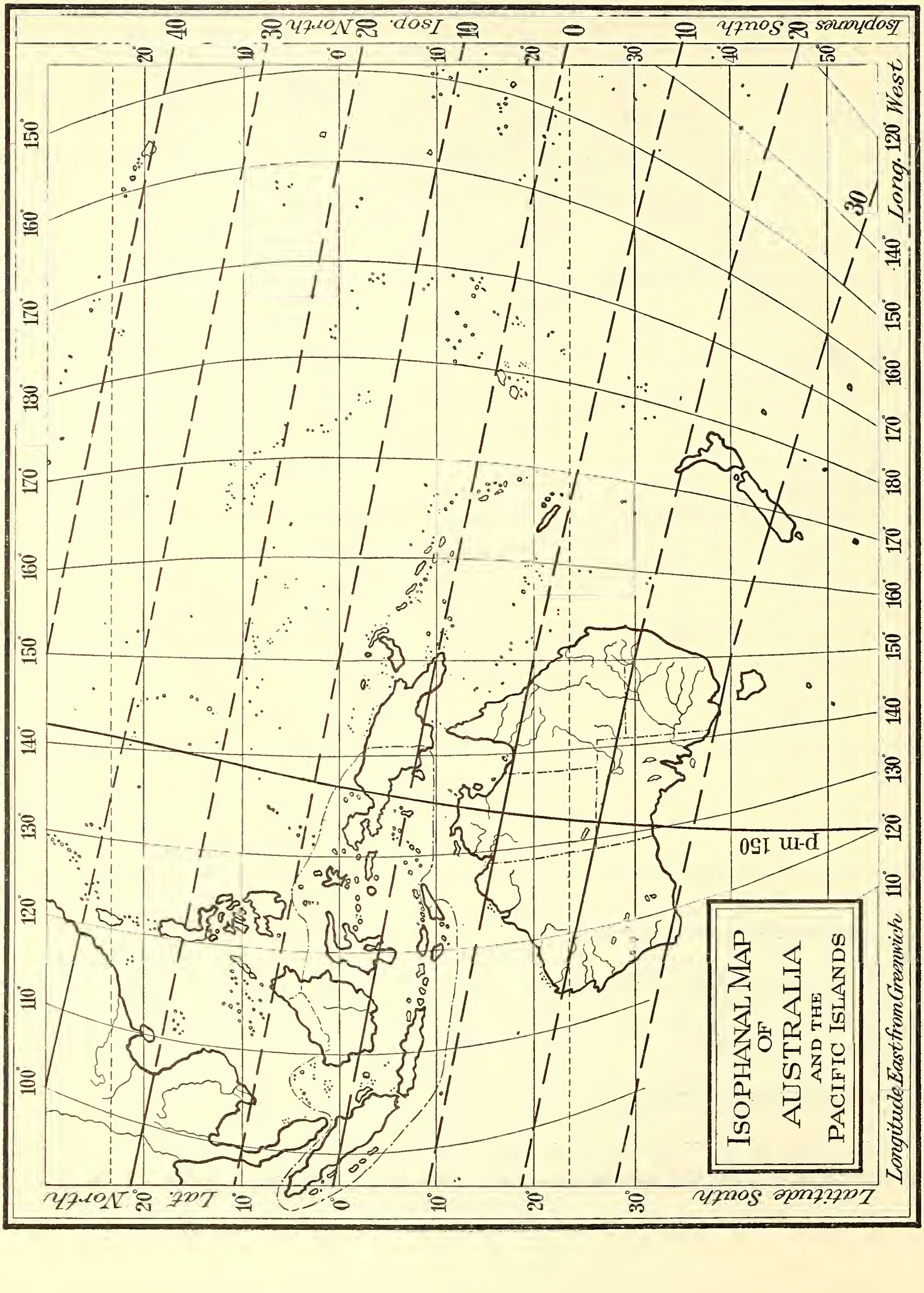

FIGURE 5.—Isophanal map of Australia and the Pacific islands.

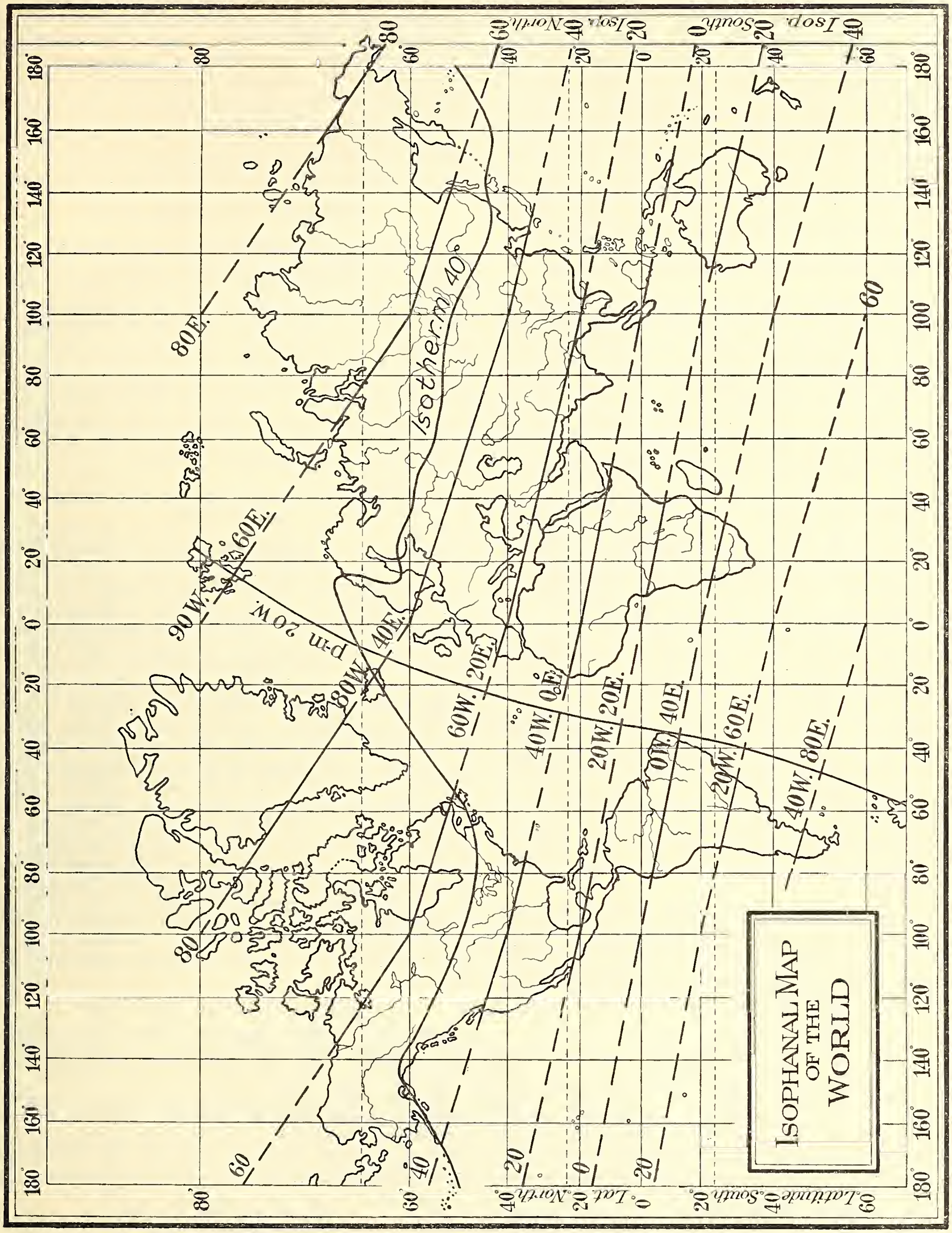

FIGURE 6.—Isophanal map of the world, with isotherm 40° F.

This principle of lines of equal effect at sea level, or at any given level across the continents, indicates that if the surface of all of the present land areas of the world were at the same level, the lines of equal phenomena would be in accordance with the requirements of the bioclimatic law as represented by the isophanes. It is, therefore, interesting to speculate on what the bioclimatic conditions might be if there were continuous land across the space occupied by the North Atlantic and by Behring Strait. Would there be semitropical conditions across the areas now occupied by Iceland, Greenland, and northern North America to the one hundred and sixtieth meridian, as paleontological evidence indicates formerly prevailed north of the Arctic Circle during one or more geological periods?

ISOPHANES AND PARALLELS OF LATITUDE

From the foregoing it will be recognized that (*a*) the isophanes as parallel lines across the continental areas of the world represent geographic coordinate constants relative to the modifying effects of major astronomic and physiographic causes, and thus serve as lines of reference by which both the major and minor effects may be interpreted and the relative intensity of the influences of the modifying causes may be measured and expressed in units of time, temperature, or distance; and that (*b*) the parallels of latitude around the world and continuous across both continental and oceanic areas represent geographic constants relative to major astronomic causes alone, and thus serve as lines of reference by which the major unmodified causes of astronomic law may be interpreted and compared with the modified causes and effects, as represented by bioclimatic and related terrestrial laws.

Thus the isophanes represent the effects of astronomic influences as modified by the present unequal distribution of land and water, as one of the major causes of warm and cold ocean and air currents, which in turn are factors controlling the character and geographical distribution of terrestrial climates and seasons, and consequently the plant and animal life of both land and water; just as we find in agreement with the isophane requirements, relative to a given parallel of latitude, warmer temperature and corresponding bioclimatic conditions on the western coasts of the northern continents extending further north than their latitude requirement constants, and on the eastern coasts further south.

It is shown also by the isotherms that, while for a given parallel of latitude it is often much warmer toward the western coasts of the northern continents and cooler toward the eastern, it is the reverse for the continental areas of the Southern Hemisphere, in that it is cooler toward the western, and warmer toward the eastern, coasts.

PHENO-MERIDIANS

With the northwest-southeast course of the isophanes representing lines of equal phenomena, it may be assumed that lines of advance and retreat of seasonal phenomena vary from the meridians of longitude much as the isophanes vary from the parallels of latitude; such lines, therefore, would be at approximately right angles to the isophanes and may be designated as pheno-meridians, numbered to correspond with the meridian of longitude crossed by them on the forty-ninth parallel north, as pheno-meridian (*p-m*) 100w (fig. 1), pheno-meridian 50w (fig. 2), pheno-meridian 100e (fig. 3), pheno-meridian 40e (fig. 4), pheno-meridian 150e (fig. 5), and pheno-meridian 20w (fig. 6). Since, however, the purpose of pheno-meridians is simply to indicate the poleward and equatorward trend of movements of seasonal phenomena, they are not of sufficient importance to be shown on all isophane maps. Moreover, since geographic positions are defined and located by latitude and longitude, or by isophane and longitude; since time and distance east and west are computed by degrees of longitude; and since in bioclimatics distances poleward and equatorward are computed for the isophanes by degrees of latitude on the meridians of longitude, the pheno-meridian is not an essential element of the system.

ISOPHANES FOR MINOR AREAS

Usually it is not practicable to draw isophanes on a map of a continent or a major political division at intervals of less than 5° to 20°; but on maps of minor political divisions it is found best to represent them at intervals of 1° or of 15′; but instead of designating the quarters as 15′, 30′, and 45′ the equivalents in decimals of 0.25°, 0.50°, and 0.75° are preferable in practice. Thus the 0.25° is adopted as the lowest unit of latitude or isophane distance, because in bioclimatics it is not practicable to distinguish differences in time, temperature, seasonal events, etc., in less than 0.25° of latitude, or its equivalent of 100 feet of altitude.

ISOPHANES AND LATITUDES OF THE TABLES OF CONSTANTS

In all tables of isophane constants computed by the standard unit constant rates in time, temperature, or distance, the given *isophanes are in degrees of latitude* and correspond in their numerical designations with those of the parallels of latitude intersected by them on the one hundredth meridian of longitude east and west of Greenwich. The constants, therefore, as computed for a given range of isophanes, apply alike to latitudes of the same numerical designation. For any position on the one hundredth meridian east or west, the isophane and latitude position constant will be the same, but owing to the departure of an isophane of a given number from a parallel of the same number east or west of the one hundredth meridian at the rate of 1° of latitude to 5° of longitude (fig. 9), the isophane and latitude constants for a position on any meridian east or west of the one hundredth will differ with distance from it in degrees of longitude, and this difference will be equivalent in degrees of latitude to the difference between the number of the position isophane and that of the position latitude relative to the parallel of the same number as the position isophane, as illustrated in figure 11.

PREFERABLE TO UTILIZE THE ISOPHANE

With the complete coordination of isophane and latitude constants of a table computed for a given range of isophanes, but with the zonal constants relative only to the isophanes, it is preferable to utilize the isophane constants as the standard basis of reference to find the variation of a position record from its isophane or latitude requirement constant, and the thermal, bioclimatic, or season zone or zonal type it represents.

THE BIOCLIMATIC BASE

GEOGRAPHIC POSITION

The bioclimatic base (fig. 7), designated as the intercontinental base for bioclimatic research and reference,

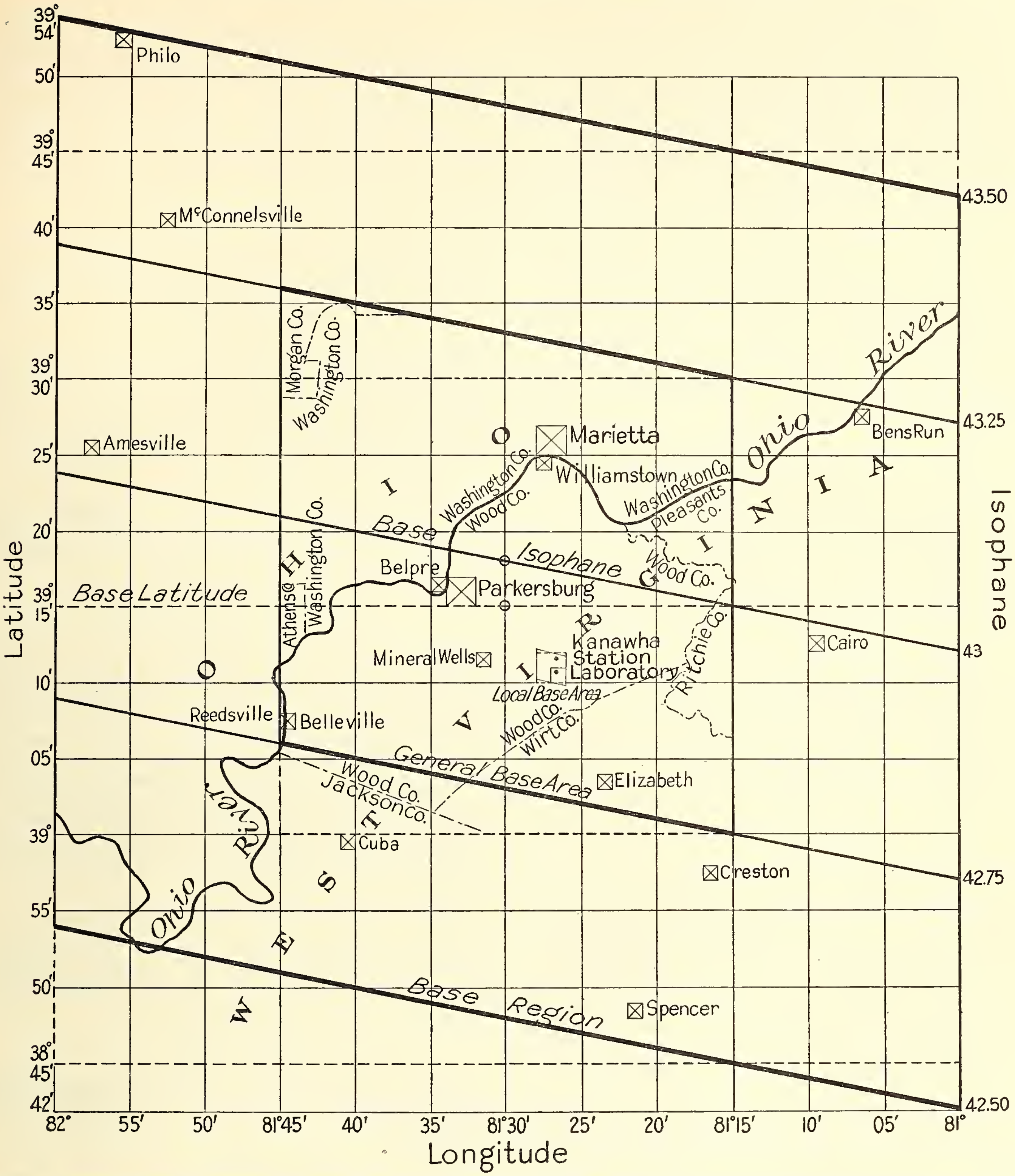

FIGURE 7.—Geographic position of the Kanawha Farms intercontinental base station, the local intercontinental base area, with general intercontinental base area, and the intercontinental base region, with reference to latitude, longitude, and isophane.

and utilized in the development of the bioclimatic law and the science of bioclimatics, includes the following:

1. The *base station and specific local base area, designated as the Kanawha Farms intercontinental base station*, includes (*a*) the station laboratory and comes within the quadrant of latitude 39°10′ to 39°11′ and longitude 81°26′ to 81°27′, with an average altitude of about 600 feet above sea level, and (*b*) the specific local area, designated as the Kanawha Farms Local Intercontinental Base Area, within the quadrant of latitude 39°10′ to 39°12′ and longitude 81°26′ to 81°28′, with altitudes ranging from 580 to 935 feet above sea level.

2. The *general intercontinental base area* comes within the quadrant of latitude 39° to 39°30′, longitude 81° 15′ to 81°45′, and isophane 42.75 to 43.25. This

includes the cities of Parkersburg, W. Va., and Marietta, Ohio, with their Federal meteorological stations, and a range in altitude from about 550 to 1,200 feet.

3. The *intercontinental base region* comes within the 1° quadrant of latitude 38°45′ to 39°45′, longitude 81 to 82, and isophane 42.50 to 43.50. This includes in West Virginia all of Wood, Wirt and Pleasants, and parts of Tyler, Ritchie, Calhoun, Roane, Mason, and Jackson Counties, and in Ohio all of Washington, and parts of Monroe, Noble, Guernsey, Muskingum, Morgan, Athens, and Meigs Counties.

PHYSIOGRAPHY

The physical features [7] of the base region represent a section of the Appalachian highland division, plateau province, and Kanawha section, as characterized by "matured plateau of fine texture, with moderate to strong relief."

The major drainage features (fig. 8) are the Ohio, Little Kanawha, and Muskingum Rivers, with their

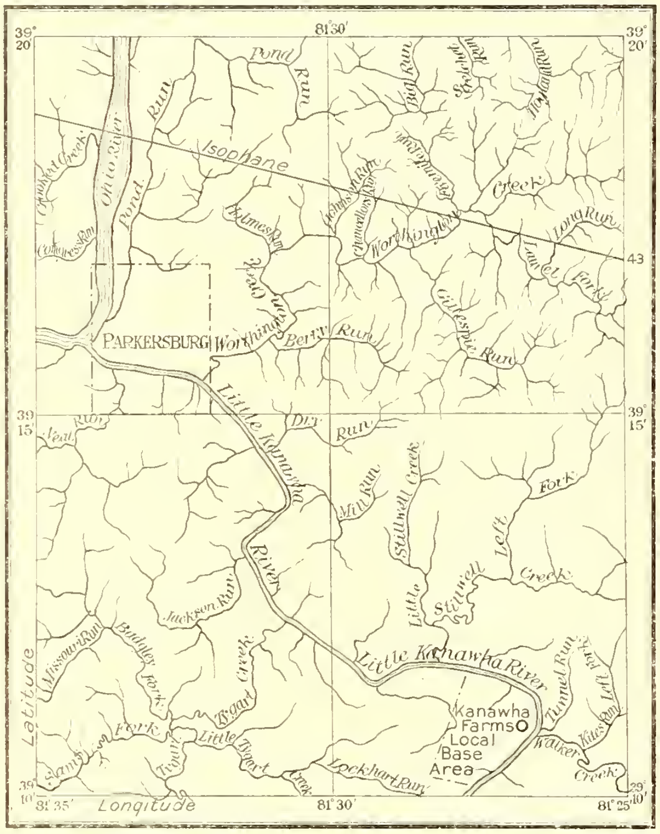

FIGURE 8.—Map of the drainage of part of the general base area.

moderately broad to narrow valleys and alluvial soils; and the minor features are the many creeks and brooks with innumerable ravines in a hilly region, much of which is wooded with second-growth trees and shrubs. This relief gives good air-drainage and provides opportunities for temperature fluctuations and inversions. The elevation above the sea ranges from about 550 feet at the low-water stage of the Ohio River to a general level of the plateau of about 1,000 feet, with some hills in the east rising to between 1,200 and 1,400 feet, and with a general average of about 600 feet for the lowland positions.

[7] Map of physical divisions of the United States, Geological Survey, U. S. Department of Interior.

GEOLOGY AND SOILS

The geological features are of the upper Carboniferous or "Permo-Carboniferous", designated as the Dunkard series of West Virginia, characterized by sandstone and shales with limestone at and near the 900-foot levels and summits of the hills.

The soils range from the alluvial gravel, sand, silts, and clay of the river valleys to sand and shaly loams and heavy, red Upshur clays, with or without lime, on the hills.

FLORA

The natural vegetation is of the oak-hickory and pine forest type, with persimmon, sassafras, dogwood, redbud, and sumac forming the small trees and shrubs.

CLIMATE

The climate of the base region is transitional between the major continental type of the Great Mississippi Basin to the west and the mountain type of the Allegheny Mountains to the east, with well-balanced warm and cold temperatures, and rainfall distributed throughout the year.

SEASONS

The seasons, like the climate, are intermediate between those of hot summers and cold winters of the continental basin and the relatively milder winters and cooler summers of the mountains.

FROST AND FROSTLESS PERIOD

The relative dates of latest killing frosts in spring and earliest in autumn, and the length of the frostless season—controlled by the broken relief of the hills which often enclose the valleys of the minor streams and the moderately broad valleys of the rivers with consequent inversion of temperature—are exceedingly variable and often show a wide range within short distances. The same is true of the range in low temperatures. For example, the minimum temperature at Kanawha Farms is often 10° to 15° lower than at Parkersburg; often killing frosts occur a week or 10 days later in spring and earlier in autumn at Kanawha Farms than in Parkersburg.

BIOCLIMATIC ZONES AND ZONAL TYPES

In general, the local region represents the middle section of bioclimatic minor zone 4 of major II (part 2), with but little variation in warm and cold, and other bioclimatic types of the minor zones.

AGRICULTURE

The prevalent type of agriculture is that of grazing, dairying, poultry raising, etc., with fruit culture on the highlands and general farming and truck growing in the river valleys.

HISTORY OF EVENTS LEADING TO THE SELECTION OF THE INTERCONTINENTAL BASE

About 1920 the Kanawha Farms local area was selected as an intercontinental base, and from its records the requirement constants of the bioclimatic law have been computed. In 1923 it was designated as a permanent field station of the Federal Bureau of Entomology for bioclimatic research. The selection of this local area as a base station was due to the fact that so much of the writer's work on entomology, phenology, and bioclimatics had been done here. Indeed, a large part

of the development of the science of bioclimatics is based on data collected and investigations carried on here since 1884, or during a period of about 50 years.

The area was further extended to form a general intercontinental base in order to include the long-established Federal meteorological stations at Parkersburg, W. Va., and Marietta, Ohio. This extension to include the region embraced within the $1° \times 1°$ geographic quadrant thus permits one to secure averages of recorded meteorological and climatic data which are representative of this section of the Appalachian Plateau region.

While the selection of these areas to represent an intercontinental base for bioclimatic records was due only to the fact that it had been utilized so long in the study of bioclimatic problems and the development of the science, it has for many other reasons proved to be one of the best that could have been made. Results of a great many test examples have indicated repeatedly that its geographic position, physiographic features, climate, weather, seasons, plants, animals, bioclimatic zone, and agriculture constitute averages which are as nearly representative of an ideal bioclimatic complex as could be expected at any other position on the continent of North America. It occupies a central position in the intermediate or temperate zone designated as major II; it is intermediate between two major types of climate, continental to the west and mountain to the east, with the four seasons about equally divided; and it has a flora and fauna characteristic of a humid temperate zone and climate.

BASE RECORDS

The records of thermal, phenological, and other bioclimatic observations, together with those of studies and researches within the local areas and general region, are designated as *base records* or *base data* for the base isophane 43 and base altitude of 600 feet above sea level, from the averages of which the standard tables of constants relative to this base are computed for the continental areas of the Northern and Southern Hemispheres, to serve as the uniform coordinate system of reference for the comparison of data for any other geographic position or area in the world.

The records of the local base area and the Kanawha Farms base station, with their centers on or near meridian 81°27′ in latitude 39°11′, and about midway between isophanes 42.75 and 43, are referred to isophane 43 as representing the central or *base isophane* and central or base latitude 39.25°.

The base altitude of 600 feet on the base isophane 43 is taken as representing a base level for the local and general area and the region quadrants. Thus all base data in broad averages are relative to the base isophane 43 and base altitude 600 feet, as representing the center of the general base area and region to which all bioclimatic data of any other position or quadrant are relative through their position constants.

PRINCIPLES, SYSTEMS, AND METHODS OF APPLICATION

PRINCIPLES

Among the principles of applied bioclimatics, those of special importance are the following:

1. THE BIOCLIMATIC ISOPHANE

This principle is of special importance in representing the basic requirements of bioclimatic law in the departure of lines of equal bioclimatic phenomena from the parallels of latitude across the continental areas of the world.

2. THE BIOCLIMATIC BASE POSITION

This principle assumes that the records of bioclimatic elements at a given geographic position may be utilized as basic units of reference for the comparison of records of the same elements at any other position, under a standard system of coordinate requirement constants of the bioclimatic law, in which the variations of the records from their respective constants serve as indices to the relative intensity of the modifying influences relative to the base in causing the departure from the requirement of the law.

3. THE REPRESENTATIVE RECORD POSITION

This principle assumes that a geographic position at which time or temperature records are kept for a period of years is representative of the local area, and that the average of the records at a number of record positions within a local or general region is representative of the region.

4. THE NONRECORD POSITION

This principle assumes that, while there may be no records for many positions coming within an area or region represented by one or more record positions, the nonrecord positions are in general subject to the same modifying influences, so that the variations of records of the record positions from their constants serve as indices to the variations to be expected at the nonrecord positions.

5. THE RECORD VARIABLE

The principle of the record variable is the same as that of the record position, in that it represents the modified effects of the causation complex and thus serves, with its variation from its constant, as an index to the interpretation of bioclimatic conditions for both the record and nonrecord position and for the local and general area or region it represents.

6. THE MEAN OR AVERAGE

This principle assumes that the bioclimatic features of a place, area, or region represent the effect of an average influence of the major and minor continental, regional, and local controlling factors, and therefore it is on the average of the records of different subjects for a period of years, rather than on the records of a single season or year, that interpretations and conclusions are to be based. The principle of the average assumes also that the range of error in the records is reduced to a more reliable basis for interpretations and conclusions. This is especially true in comparative bioclimatics, in which the average thermal, time, or distance requirements of the law are represented by computed constants for comparison with averages of record variables.

7. RANGE OF ERROR IN RECORDED BIOCLIMATIC DATA

This principle assumes that any bioclimatic element in nature, as observed and recorded in terms of time, temperature, or distance, is subject to a greater or less range of error, but that averages tend to reduce this range to a reliable basis for interpretation.

8. ALLOWABLE RANGE OF ERROR

This principle assumes that, since there is always a greater or less range of error in recorded data, there must be a permissible, limited range of error in the interpretations and conclusions based on such data.

This allowable error varies with the range in the relative requirements for precision, or in the purposes to be served. Thus in a science such as astronomy, the error in some cases must be reduced to a minimum, while for certain subjects in climatology, meteorology, and biology there is often a wide range of allowable error, and yet the data may serve for a correct interpretation even better than if attempts are made to achieve an impossible degree of precision.

In bioclimatics, dealing as it does with actual or interpreted averages, the requirement constant of the law represents an assumed or theoretical expression of precision, and the variable quantity (whether climatic, biologic, or geographic) represents a more or less wide range of variation which must be recognized. For example, in recorded temperature there is often a wide range of difference between that for one place and that for another place only a short distance away. Moreover, except in the effects of frosts, it is rarely possible to judge or record differences in effects relative to a given average thermal or time element within less than 0.25° to 0.50° F., or 1 to 2 days of time at any given place. It is well known that there is very often a wide range of error between the forecasts of weather conditions and the subsequent events; yet a very valuable service is rendered by such forecasts.

For other examples of unavoidable error, we may mention record dates of events in the seasonal development of plants, insects, etc., which in general must involve a range of error of 1 to 4 days as to the exact time of occurrence, because the change from one event to the next succeeding one usually cannot be detected by the eye within much less than 4 days. Even the average for a period of years will seldom reduce the range of error to less than 1 day. In a like manner movements of seasonal phenomena, by distance in latitude or altitude, cannot be detected and expressed in units of time for less than 0.25° or within the equivalent unit of altitude of 100 feet. It is the same with attempts to define the latitude or altitude range and limits of a species of plant or animal, a type of climate, or a biologic zone, in which a very much wider range of error is involved than in either of the preceding subjects. And finally there is, as commonly recorded and expressed, a more or less wide range of departure from the facts in records of geographic positions by latitude, longitude, and altitude, as there is also in representations on maps or in interpretations of geographic positions from different maps of the same area. Yet these climatic, biologic, and geographic records all serve most important scientific and practical purposes.

So that, while accuracy in records is desirable within the lowest range of error, in bioclimatics records of temperature within 0.25° to 1° F., time within 1 to 4 days, distance in latitude by isophane within 0.25 to 1°, and altitude within 100 to 400 feet serve their purpose quite as well as if they were reduced to lower decimals, as is clearly shown in test examples.

Bioclimatics deals with coordinate standard quantity units, as for temperature in lowest units of 0.25° F. or equivalent degrees centigrade, latitude by isophane in lowest units of 15′ or 0.25°, time in lowest units of 1 day or 24 hours, and altitude in lowest units of 100 feet or equivalent meters; in other words, any record with fractions or numbers lower than the standard units are referred to the nearest higher or lower standard unit.[8]

[8] In the unit constant rates and in the standard tables of thermal and time constants, small fractions are included to provide for progressive gradations to correspond with the 0.25°, 0.50°, 0.75°, or 1° higher or lower isophane.

9. THE BIOCLIMATIC CONSTANT

This principle assumes that the requirements of a law may be expressed in specific invariable quantities, designated as constants, to serve as units by which departures of recorded variables from the requirements of the law are measured and interpreted. Thus for the bioclimatic law its requirement constants are expressions of its requirements for distance, time, or temperature. In other words, it is a principle by which the ideal of a natural law is expressed and the departures due to modifying factors are measured.

10. THE TABLE OR CHART OF BIOCLIMATIC CONSTANTS

This principle and system is represented by standard thermal, time, and distance constants for a given range of sea-level isophanes, to serve as a uniform basis of ready reference for the comparison of records to determine the extent of their departures or variations from the requirements of the law.

11. VARIATIONS FROM THE CONSTANTS

This principle assumes that the variation of a record variable from its position constant is an expression and measure of the relative intensity of the modifying influences of the major, minor, or local causation complex at a given position.

12. THE VARIATION INDEX

This principle assumes that the variation of a record from its constant is an index to the modifying causes and factors, and to the effects in temperature, dates of seasonal events, altitude limits, etc., to be expected at the record and corresponding nonrecord positions.

13. THE EQUIVALENT UNIT

This principle assumes that because the unit constant rates for temperature, time, and distance are coordinates of the law, any one unit has its equivalent in any other—as 400 feet is equivalent to 1° of latitude or isophane, 4 days of time, or 1° F. of the average annual temperature, and vice versa.

14. THE EQUIVALENT ISOPHANE OR LATITUDE

This principle assumes that the altitude of a position above sea level is equivalent to a higher isophane or latitude at sea level, at the rate of 1° of latitude to 400 feet.

15. THE RECORD ISOPHANE OR LATITUDE

This principle assumes that the record in numerical units of time, temperature, or altitude distance for a position, when referred to the same numerical unit in a table of constants, gives the corresponding isophane, which is designated as the record isophane or record latitude for the position.

16. THE ZONE AND ZONAL TYPE

The principle of the bioclimatic and season zone assumes that the determined characterizing elements come within specified ranges of average annual mean temperature, and that of the zonal type assumes a local or regional modification of its zone as indicated by temperature other than the annual mean, or by seasonal climatic, biologic, or any other bioclimatic element.

OUTLINE OF METHOD OF PROCEDURE

Methods of procedure in the application of bioclimatic principles are based on certain essential elements and rules, which may be modified to meet general or specific requirements of research or practical application. The more important methods of procedure may be outlined as follows:

1. CARD CATALOG OF GEOGRAPHIC POSITIONS

In dealing with a large number of record positions in a region or country of one or more continents, it is important that a card catalog of the essential recorded thermal, time, or distance data for each record position be prepared and filed for ready reference. While records of different closely related subjects may be included on the same card, it is usually best to utilize separate cards for different major subjects.

The elements of *thermal record card A* are: Name of the position with the index, *pi* (position isophane) and *plo* (position longitude), and country by which the cards are filed according to isophane and longitude, with guide cards giving the 1° isophanes. On the second line the geographic position is given in *pl* (position latitude), *plo* (position longitude), and *pa* (position altitude); this is followed by *le* (the latitude equivalent to *pa* [9]), which plus *pi* equals *ei* (the equivalent isophane); for comparison with the *ri* (record isophane) or the *mri* (modified record isophane); and *ZC* gives the zonal constant for *ei* in any table giving zonal constants. On the third line, *yrs.* gives the number of years represented by the subject records; *Subject*, the record thermal subject; *Sym.*, the standard letter symbols for the thermal subject; *Rec. ° F.*, the temperature records to tenths of a degree Fahrenheit; *App. Tab.*, the number designations of appendix tables of constants to which the records are referred to find the *ri* record isophane by the subject constant coming nearest to the record in tenths of a degree. In this same line *me* is for the modified equivalent of *le; mri*, the modified record isophane for positions at or above 2,000 feet, as explained under example card C.; *lev*, the variation in degrees of latitude of *ri* or *mri* from *ei*, which is equivalent to the variation of the position record from the requirement position constant, in which minus (−) indicates a lower and warmer, and plus (+) a higher and colder latitude;[10] *ed*, the variations in equivalent days to *lev* (as *lev* × 4 equals) *ed* with plus signifying warmer and minus colder than the requirement constant; and *eft*, the equivalent variations in feet of altitude to *lev* and *ed* (*lev* × 4°, or *ed* × 100 feet), with plus signifying higher and warmer, and minus lower and colder than the requirement constant, which has special reference to the higher and lower position of the zone or type relative to the zonal constant (*ZC*) for the equivalent isophane (*ei*). The *eft* element and duplication of subject symbols are not entered on the regular index cards but are given here to show the coordinate relations. Under *zone, Sym.* gives the subject symbols for the *a* zone, and *w*, *c*, etc., the types represented by the subject records and record isophanes for the given geographic position. *Zone, type*, and *mz*, give the minor zone and the *w* to *f* and *h* to *j* zonal types, as represented in the scale of zonal constants of the tables of constants by the *ri* or *mri* for each subject (see Classification of Bioclimatic Zones, p. 95, and Classification of Zonal Types, p. 99, for further discussion of terminology). It will be noted that for subject *g*, lowest recorded temperature, the type is indicated by the record −27° (see appendix sechedule 1 of lowest temperature types).

In the lower space, *months* gives abbreviations for the months of the year; *monthly means*, the normal mean for each month; *annual*, the average for the year, with the warmest and coldest months underlined; while *effective sum* gives the sum in degrees Fahrenheit of the monthly means for each month above 43° F., with the effective sum for the annual period. It will be noted that this principle of the sum of the monthly means differs from the effective sum, or "thermal constants" of literature, in that it is computed from the monthly instead of the daily means. On the lower line is given the authority for the record data.

The symbols as given in this sample record card are adopted as standards in bioclimatics, and are utilized throughout this work without further explanation.

Example of Thermal Record Card A

Parkersburg, W. Va.; *pi* 43.00, *plo* 81. N. A. U. S.

pl 39.25°, *plo* 81.25°, *pa* 600 ft., *le* 1.50, *ei* 44.50. ZC II.4

Yrs.	Subject thermal	Sym.	Rec. ° F.	App. tab.	ri	me	mri	Variations: lev	Variations: ed	Variations: eft	Zone: Sym.	Zone: Type mz
32	Annual mean	*a*	54.0	3	43.75	--------	--------	−0.75	+3	+300	*a*	Zone −.4
32	Warmest monthly mean	*w*	75.1	3	44.00	--------	--------	−.50	+2	+200	*w*	Type −.4
32	Coldest monthly mean	*c*	32.6	3	44.00	--------	--------	−.50	+2	+200	*c*	Type −.4
32	Annual maximum	*d*	63.7	4	45.00	--------	--------	+.50	−2	−200	*d*	Type .4
32	Warm monthly maximum	*e*	85.4	4	45.25	--------	--------	+.75	−3	−300	*e*	Type .4
32	Highest record	*f*	106.0	4	44.50	--------	--------	0	0	0	*f*	Type .4
32	Lowest record	*g*	−27.0	schedule 1		--------	--------	--------	--------	--------	*g*	Type −27
32	Cold monthly minimum	*h*	24.2	4	44.25	--------	--------	−.25	+1	+100	*h*	Type −.4
32	Annual minimum	*i*	44.3	4	44.00	--------	--------	−.50	+2	+200	*i*	Type −.4
32	Monthly mean sum +43	*j*	160.5	5	44.00	--------	--------	−.50	+2	+200	*j*	Type −.4

Yrs.	Months	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
32	Monthly means	32.9	<u>32.6</u>	43.1	53.0	63.5	71.5	<u>75.1</u>	73.7	67.7	55.9	44.0	35.1	54.0
32	Effective sum	--------	--------	.1	10.0	20.5	28.5	32.1	30.7	24.7	12.9	1.0	--------	160.5

Authority for records, U. S. Weather Bureau Bull. W, 1926.

2. LISTS OF GEOGRAPHIC POSITIONS

Another stage in the process of assembling recorded data for comparison with computed constants is to make

[9] All isophane distance is measured in degrees of latitude, as is also variation in isophane.

[10] Variations in equivalent degrees of latitude are preferable to variations in degrees of temperature because comparison between equivalent latitude variations for time, thermal, and distance subjects with differences in their modified unit constant rates provides for a more uniform and correct basis of interpretation.

a list, or assemble the record cards, of the geographic positions involved in a given line of study or research.

If record cards are available, the list may be made directly from the cards, but if these are not available the list may be made directly from the published data. In either case the form of the list would be as represented by time subjects in examples 1 and 6; by thermal subjects, in example 8; or altitude distance subjects as in example 15.

3. TABLES OF CONSTANTS

An essential element of the system of bioclimatic constants is formed by tables of computed time, thermal, and distance constants such as those given and fully explained in part 3.

The process of computing requirement constants of the bioclimatic law for a local, continental, or intercontinental table of constants is simply to take the base record for a given subject and compute the constants for the isophanes above and below the equivalent base isophane by the standard unit constant rates, as given and explained under the appendix tables of constants for time, temperature, and distance subjects.

Since the standard tables of constants, as given in the appendix, are already computed for some of the principal subjects, the need for further computations is for subjects which are not included in the standard tables. Such additional subjects include the hundreds of bioclimatic elements that may be expressed in numerical units of time, temperature, or distance, and for which unit constant rates of variation with distance in degrees of latitude may be applied to represent the requirements of the bioclimatic law, or of any other law of cause and effect.

Whenever possible or practicable, the standard unit constant rates in time, temperature, and distance should be utilized in order that results of the bioclimatic method in the investigation of any subject may be directly comparable with results of investigations of any other subject by the same method. It is important to keep in mind (*a*) that a given series or system of constants is assumed to represent a broad continent-wide average requirement of a natural law and that the constants are based on the results of studies of continent-wide averages of observed facts and evidence, as represented by records covering the widest possible east-to-west, and equatorward-to-poleward, distances in degrees, and vertical altitude ranges in feet; (*b*) that, therefore, whether or not the constants are truly representative of the law, the system serves as a uniform basis for the comparison of records; and (*c*) that the variations of the records from the specified requirements is a true measure of the relative intensity of the causation influences at the given record position.

In order that constants for all subjects may represent a coordinate system, it is of special importance to retain the standard rates and to make no changes in them unless need for such change is definitely proved to be essential.

4. COMPARISON OF POSITION RECORDS WITH POSITION CONSTANTS

This process in the application of bioclimatics is to find the variations of the records from their requirement-position constants to serve as variation indices to the interpretation of results. The procedure is to utilize as far as possible the record card index where all of the computations to variations, zones, etc., are found; otherwise, the procedure is the same as in the preparation of an index card, as explained under example cards A, B, and C.

Another method of procedure without reference to tables of constants in the comparison and study of local data is illustrated by, and explained under, examples 89 and 90 of part 2 (p. 150).

5. TABULATED RESULTS

This process includes the tabulation of results of process 4 for comparative study and interpretation of the variations, etc., as in succeeding examples.

6. CHARTED RESULTS

This process is to give a graphic expression and illustration of the results of processes 4 and 5, as shown in figure 12 and other figures.

7. APPLICATION OF THE VARIATION INDEX

The variation of a position record from its position constant, when the record is applied directly or as its equivalent in latitude degrees, is designated as the variation index.

Its principal application is in the interpretation of bioclimatic elements for nonrecord positions within an area or region represented by a record position or a number of such positions. In case there is but one record position within a given area, the variations of the given subjects are utilized, but when there are several record positions within a local region or geographic quadrant, the average of the variations for each subject for all of the positions is utilized as in examples 17 to 23.

Thus the variation index serves as a more or less reliable guide to the interpretation of the bioclimatic zone, zonal types, and other bioclimatic features which may be expected to prevail at the nonrecord positions, or within the represented area or region as a whole.

8. INTERPRETATIONS OF VARIATIONS

The special significance of the variation of the record variable from its position constant is in the fact that it represents, and is a measure of, the modifying influence of the local or regional causation complex, and thus serves as an index to the interpretation of the bioclimatic features of the record and nonrecord positions within the range of the prevailing type of influence. This type of influence is judged by (*a*) the extent of the variations from the requirements of the law relative to a given subject, or average of a group of subjects, (*b*) the zone and zonal types, and (*c*) such other facts and evidence as are available from any reliable source as to the departure from their normal or average elements of the climate, seasons, native and introduced plants and animals, and their ecological association, types of agriculture, etc., as discussed in the following section.

TESTS OF BIOCLIMATIC PRINCIPLES AND METHODS

The object of this section is to give concrete test examples of principles and methods, with special reference to the relations between the requirement constants of the bioclimatic isophane and the astronomic parallels of latitude.

METHODS OF TESTING BIOCLIMATIC PRINCIPLES AND COMPARING RESULTS BY THE ISOPHANE-LATITUDE CHART PRINCIPLE

As a basis for procedure in the test of bioclimatic principles and methods, and in the comparison of results, it is necessary to have a clear picture and understanding of the coordinate relations between the isophane and parallel of latitude principles as illustrated by figures 9 to 11.

It will be noted that the distance in degrees of longitude from 75 on the east coast to 125 on the west coast of North America is 50°, and the distance north and south is 10° of latitude; that isophane 43 is 5° south of parallel 43 on meridian 75 and 5° north of it on meridian 125; and that the departure of the base isophane from the base parallel ranges from 0° at B to 1.25° south on meridian 75, 3.75° north of it on meridian 100, and 8.75° north on meridian 125; also that isophane 43 is 3.75° south of parallel 43 on the base meridian 81.25°,

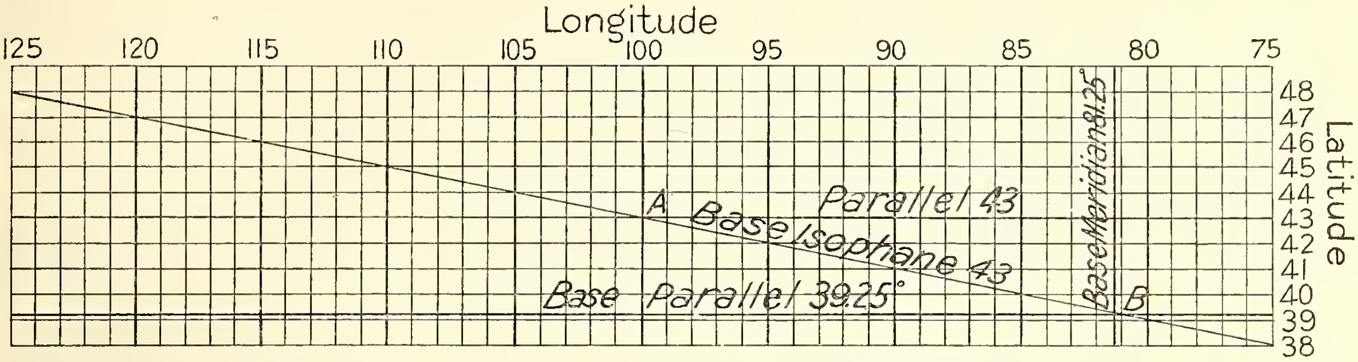

FIGURE 9.—Coordinate relations between the parallels of latitude, meridians of longitude, and the isophane.

The objects of figures 9 to 11 are (1) to give a clear idea of the relations between the bioclimatic isophane, the astronomic parallels of latitude, and the meridians of longitude, with special reference to the one hundredth meridian and to the base meridian 81.25° of the intercontinental base position; and (2) to illustrate the basic principle of the isophane-latitude chart in the comparison of variations in time, temperature, and distance records from the requirement constants of bioclimatic law as represented by the isophanes and of astronomic law as represented by the parallels of latitude.

The principles of the isophane-latitude chart method are (*a*) in representing the isophane, parallels, and 0° on the one hundredth meridian, and 5° north of it on the one hundred and twenty-fifth meridian.

With this illustration of the coordinate relations of the isophane to the parallels of latitude and meridians of longitude, it will be recognized that the equal numerical relations of the isophanes and parallels on the one hundredth meridian and the unequal numerical relations on all other meridians, including the base, must hold for any isophane-latitude chart.

Figure 10 shows the method of utilizing the 0.25° for the isophane, latitude, and longitude on the 1 to 5 ratio in a 1° latitude by 5° of longitude quadrant from longitude 80 to 85 and latitude 39 to 40, with each 1°

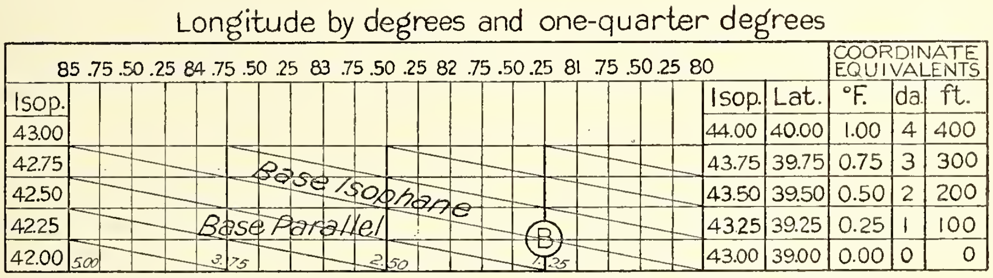

FIGURE 10.—Method of utilizing the 0.25° relations between latitude, longitude, and isophane.

meridians by straight lines instead of by curved lines as on maps; and (*b*) in utilizing a *base isophane*, a *base parallel*, and a *base meridian* to represent the coordinate constant relations between all isophanes, parallels, and meridians across a continent, in which the departure of the isophane from the parallel is at the rate of 1° of latitude to 5° of longitude.

The elements of figure 9 are the base isophane 43, base parallel 39.25°, and base meridian 81.25°, intersecting at the *intercontinental base position* B; and the base isophane 43 and parallel 43 intersecting on the one hundredth meridian at position A. The numerical designation of the parallels intersected by isophane 43 are given at intervals of 1° and those of the meridians of longitude at intervals of 5°.

latitude and longitude quadrant divided into sixteen 0.25° by 0.25° quadrants.

This chart will show how to draw 0.25° isophanes on a map of a minor political division or area from any given 1° meridian ending in 0 or 5, and at the same time preserve their coordinate relations to the standard numerical designations of the isophane.

The elements are the same as in figure 9, except that (1) the intervals are 0.25° for the latitude, longitude, and isophane; and (2) the coordinate equivalents in degrees Fahrenheit, days of time, and feet of distance above the base isophane for each 0.25° isophane are given at the right. Each of the 1×5 quarter-degree quadrants, indicated by 1.25, 2.50, 3.75, and 5.00 west from meridian 80, includes twenty 0.25° quadrants.

Figure 11 shows the relation of the numerical designations of the isophanes and parallels of latitude for a wide range of latitude and how variations from the isophane and latitude requirement constants are measured for charting the variations in figure 12; that the numerical designations of the isophanes and parallels are the same on the one hundredth meridian, but that east and west of it there is a difference of 1° between the isophane and parallel of the same number for each 5° of longitude, which difference applies to all isophanes and latitudes on the meridians, as shown by the *Isop-Lat* column to the right and *Lat-Isop* to the left; that west of the one hundredth meridian, isophane 43 is 1° higher than latitude 43, and that east of it the isophane is 1° lower for each 5° of longitude.

It is important to keep in mind that there is always a coordinate relation between the isophane, latitude, and their constants, and that, therefore, the constants computed from the base isophane are coordinates of the system and are thus available for comparing a position record with its position-isophane or its position-latitude of 20 days or its equivalent plus of 2,000 feet, their equivalent is 5° of latitude; and since as a rule thermal, time, and altitude variations are usually measured on a chart in equivalent degrees of latitude the relative position of this variation is plus 5° above the base isophane; and since the base parallel is 7.75° below the isophane on meridian 120, the corresponding variation from the latitude constant for the position is (+5 + (−) 7.75) + 12.75°. In the same way the zero adjusted to the base isophane for any other position on or near a given meridian with a given variation will give the position on the chart of the variation from its isophane constant; and, as measured from the base or any other parallel will give the relative variation from their latitude requirements, as in figures 12 to 22 and figure 24.

To facilitate measurements in 0.25° or its time or altitude equivalents, the 0.25° intervals may be marked on the edge of the 1° scale, as between 1 and 2 with the 0.25° intervals for the 1° (as in fig. 10).

A plus variation on the chart, as expressed in latitude degrees, signifies that the position record is warmer

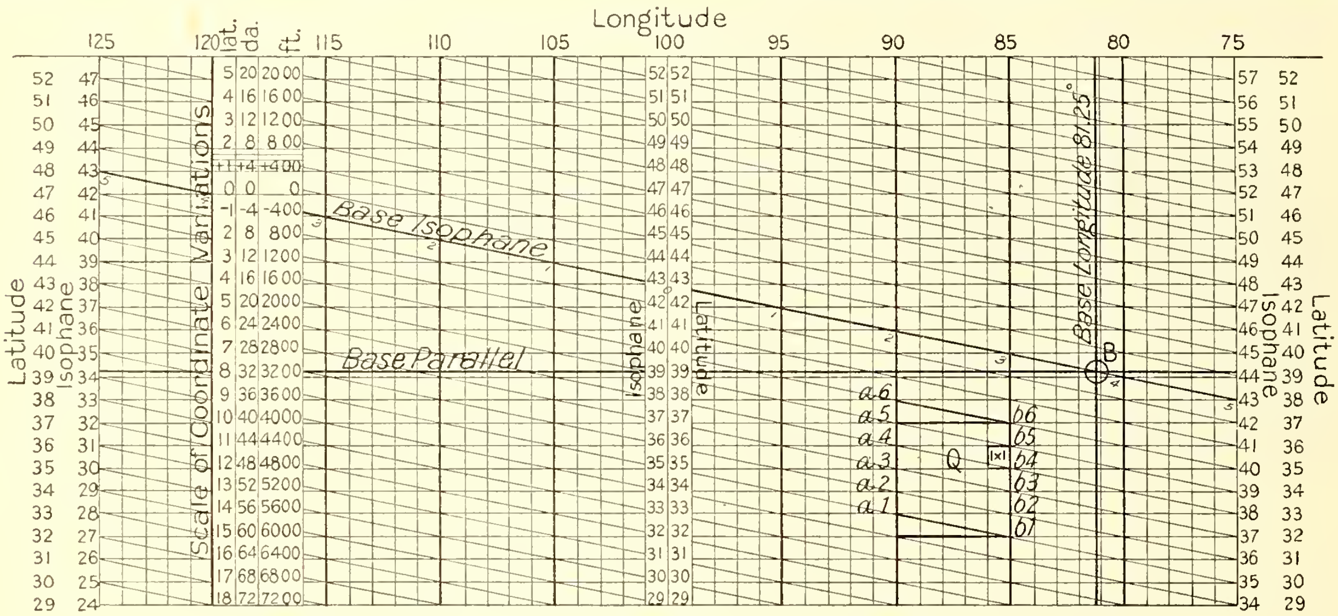

FIGURE 11.—Relations of the numerical designations of the isophanes, parallels, and meridians.

constant to determine the variations from the requirements of the bioclimatic law in one, or of the astronomic law in the other; also that the isophane and latitude constants will differ only as the numerical designations of the position isophane and position latitude differ on a given meridian.

The basic elements of this chart are the same as those of figures 9 and 10 except that they illustrate the principle of the system of coordinate relations between time, temperature, and distance elements, as shown in the scale for measuring determined variations of records from the requirement isophane or latitude constant.

The *lat*, *da*, and *ft* scale gives the coordinate equivalent variations in units of latitude degrees, days, and feet of variations from the isophane, as for meridian 120, but the scale is for a separate strip of paper with the intervals of 1° of latitude the same as those of the chart to which it is adjusted to measure on the position meridian the plus variation above the base isophane or base parallel, or the minus variation below them. Thus with the zero adjusted for position 4 west on meridian 120, latitude 47° and isophane 43, with a plus variation than the position constant, and a minus that it is colder; so that a variation of +5° of latitude on the chart is equivalent to a lower and warmer latitude, while a variation of −5° is equivalent to a higher and colder latitude. In days, a +5° variation is equivalent to (+5 × 4 days to 1°) 20 days earlier for a spring phenological event or later for an autumn event, and to a longer period between dates; while a −5° variation is equivalent to 20 days later for a spring event or earlier for an autumn event, and to a shorter period. In feet +5° is equivalent to (+5 × 400 feet to 1°) 2,000 feet higher altitude and warmer, and −5° is equivalent to 2,000 feet lower altitude and colder than that of the position constant.

Thus relative to the isophane and altitude of a position as charted a plus variation in latitude degrees, days, or feet will indicate that the position represents a warmer lower zone, earlier spring, later autumn, and longer warm period than is indicated by the position constant; while a minus variation will indicate a colder higher zone, later spring, earlier autumn, and shorter warm period.

It may require considerable study, reference to test examples, and experimental tests to thoroughly understand this apparently complicated principle of measuring and comparing variations from the requirement constants of bioclimatic law, the interpretation of relations, and its significance as applied in bioclimatics, but it is of such fundamental importance as to justify all the study that may be required to master it.

It is of especial importance to keep in mind that the unit constant *rates* of the bioclimatic law for distance in degrees of latitude (by isophane), feet of altitude, days of time, and degrees of temperature represent a *fundamental coordinate system*, in which rates, constants, and variations of records from their constants, as expressed in units of latitude, distance, time, or temperature are equivalent one to the other in their respective units.

It is also important to recognize that, for comparison of variations and interpretation of their significance, the principle of expressing variations in *equivalent degrees of latitude* is for a number of reasons preferable to expressing them in units of time, temperature, or feet (1) because of the modified rates for temperature and the generally unmodified rates for time and altitude; (2) because the equivalent isophane represents the requirement constant for the position in temperature, time, or altitude; (3) because the record isophane or modified record isophane represents the modified effects of the local causation complex of the geographic position, and also the zone and zonal type as an expression of the modified bioclimatic effects; (4) because the difference between the equivalent isophane and the record isophane or modified record isophane in degrees of latitude is a measure of the variation from the requirement constant and the relative intensity of the modifying influences; and (5) because the variation in degrees of latitude multiplied by 4 days to 1° reduces it to its equivalent variation in days, or by 400 feet to 1°, to its equivalent variation in feet of altitude.

The $5° \times 5°$ quadrant in figure 11 designated as Q is to illustrate the relations of the isophanes and parallels of latitude to a quadrant when utilized for the location of one or more record positions within it. In this quadrant the region represented comes between longitudes 85 and 90, latitudes 32 and 37, and isophanes 35 and 40, in which the $1° \times 5°$ latitude-longitude quadrant comes between b_1 latitude 32 and b_2 latitude 33, and longitudes 85 and 90, while the corresponding $1° \times 5°$ isophane-longitude quadrant comes between a_1 isophane 35 and a_2 isophane 36 and the same degrees of longitude.

In utilizing record positions within a latitude-longitude, or corresponding isophane-longitude quadrant separately, there will be involved a difference in the positions coming within the lower triangular half of the lower latitude (b_1–b_2) quadrant and in the upper triangular half of the upper isophane (a_5–a_6) quadrant, but as a rule this will make little or no difference in the average of the records or in the variation index, especially in a $1° \times 1°$ or smaller quadrant. Since, however, the isophane is adopted in bioclimatics as the standard line of reference, *the isophane-longitude quadrant should be utilized* in preference to the latitude-longitude quadrant, except under special conditions. For the application of the isophane-latitude chart principle, see figures 12 and 13, and for the isophane-quadrant principle, see figures 14 and 16.

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COORDINATE RELATIONS BETWEEN THE PLUS AND MINUS SYMBOLS AS APPLIED TO THE ISOPHANE-LATITUDE CHARTS

Because of the coordinate relations between the plus and minus signs as applied to an isophane-latitude chart it is important to keep in mind the required reversal of the plus and minus signs for the *lev* latitude equivalent variations of the record cards and examples when applied to the chart. There is also a rather complicated reversal of these signs as applied to different subjects and for different purposes as explained in the glossary, part 3.

TEST EXAMPLES BY TIME RECORDS

Examples are here given of tests by selected time records in (*a*) the relative requirements of the bioclimatic and astronomic laws; (*b*) application of the system of bioclimatic constants; and (*c*) application of the principle of the isophane-latitude chart in comparing variations from the isophane and latitude constants, and in interpreting their significance relative to the choice of the isophane as the standard basic principle of reference in bioclimatics.

TIME RECORDS IN DATES AND PERIODS IN DAYS OF WINTER WHEAT CULTURE IN THE UNITED STATES

The records of winter wheat seeding and harvest dates, and periods in days between dates, are selected for the first test example in this series because of the available records in the files of the Office of Farm Management, United States Department of Agriculture of reported dates from all wheat-growing States. These records, accompanied by State maps giving averages for counties, were transferred to the bioclimatic files in the form of State lists of positions by isophanes, pheno-meridians, and altitudes. Such data on cards can be filed either by individual positions or by averages for counties or geographic quadrants as shown in the following time record card B.

Example of time record card B

10. Wood County, W. Va.: *pi*, 43.00: *plo*, 81. N. A., U. S. Ma Mi
pl, 39.25°, *plo*, 81.25°, *pa*, 600 ft., *le*, 1.50, *ei*, 44.50. ZC II .4

Yrs.	Subject Winter wheat	Sym.	Rec. yd	App. Tab.	*ri*	Variations			Sym.	Zonal type
						lev	*ed*	*eft*		
	Seeding	*S*	272	7	44.50	0	0	0	*S*	.4
	Harvest	*H*	174	7	44.50	0	0	0	*H*	.4
	Period (days)	*P*	267	7	44.50	0	0	0	*P*	.4

Example of time record card Ba

5. Crook County, Wyo.; 43.50, 104. N. A., U. S.
44.25°, 104, 4,600 ft., 11.50, 55.00. II+.2

		S	264	7	46.50	−8.50	+34	+3,400	*S*	+.4
		H	191	7	48.75	−6.25	+25	+2,500	*H*	−.3
		P	292	7	47.50	−7.50	+30	+3,000	*P*	+4

It will be noted that the principle and elements of this time-record card are the same as for example thermal-record card A, except for the subjects and time symbols, and that this form can be used for listing data on any time subject that is represented by a table of constants, or for which constants may be computed by the unit constant rates; it, therefore, should be adopted as a standard for record index files.

This example card is for position 10 of the positions listed in example 1 and represents the base county or general intercontinental base area; while *Ba* is for position 5 of the same list, and the same symbols apply. *S* is for seeding, *H* for harvest dates, and *P* for periods in days between *S* and *H*. Under *Rec. yd* the record year dates (see appendix year-date calendar, schedule 4) are given for *S* and *H* to correspond with the month dates in example 1; *App. Tab.* is the number designation of the appendix table of seeding, harvest, and period constants to which the records are referred to find (by their corresponding constants) the *ri* record isophanes, which compared with *ei* gives the *lev* latitude equivalent variations in degrees to the variations in days; *ed* is equivalent days to *lev* (as *lev* × 4 days to 1° equals *ed*); *eft* is equivalent feet to *ed* or *lev* (as *lev* × 400 feet to 1°, or *ed* × 100 feet to 1 day equals *eft*); *Ma* is for major and *Mi* for minor zone or type; *ZC* gives the zonal constant II .4, represented in the table by the *ei* equivalent isophane; and under *zonal type*[11] the minor zone of major II represented in table 7 by the record or *ri* record isophane. It will be noted that for the base county there are no variations and that the record zonal types agree with the zonal constant, while for position 5 there are marked warmer *lev*, *ed*, and *eft* variations, and warmer record zonal types than indicated by the zonal constant for the position.

[11] See pt. 2 for a more complete discussion of zones and zonal types.

EXAMPLE 1.—*List of record positions on or near isophane 43, with county averages of winter wheat seeding and harvest dates and periods in days*

pno	County	State	Geographic positions				*S*		*H*		*P*
			pl	*plo*	*pi*	*pa*	*md*	*yd*	*md*	*yd*	*days*
1	Callam	Washington	48.00	123	43.25	100	Oct. 4	277	Aug. 18	230	318
2	Kittitas	do	47.00	120	43.00	1,800	Sept. 18	261	July 16	197	301
3	Nez Perce	Idaho	46.25	116	43.00	2,400	Sept. 14	257	July 15	196	304
4	Gallatin	Montana	45.50	111	43.25	3,900	Sept. 21	257	July 10	191	299
5	Crook	Wyoming	44.25	104	43.50	4,600	do	264	do	191	292
6	Tripp	South Dakota	43.25	100	43.25	1,800	Sept. 12	255	July 1	182	292
7	Knox	Nebraska	42.50	98	43.00	1,400	Sept. 16	259	do	182	288
8	Carroll	Iowa	42.00	95	43.00	1,000	Sept. 12	255	July 5	186	296
9	Marshall	Illinois	41.00	89	43.25	700	Sept. 15	258	July 1	182	289
10	Wood (BP)	West Virginia	39.25	81	43.00	600	Sept. 29	272	June 23	174	[1] 267
11	Barbour	do	39.00	80	43.00	2,000	Oct. 1	274	June 28	179	270
12	Page	Virginia	38.50	78	43.00	400	Oct. 12	285	June 29	171	251
13	Somerset	Maryland	38.00	75	43.00	100	Oct. 25	298	June 18	169	236

[1] BR.

Example 1 gives the names of counties and States through which the base isophane 43 passes in its course across the United States between longitude 75 and 123, with the given geographic positions in *pl* position latitude, *plo* position longitude, *pi* position isophane, and *pa* position altitude to represent the approximate average position within each county. *S* gives the average seeding and *H* the average harvest dates, in which *md* is the month date and *yd* the year date, while *P* gives the average period in days between the *S* and *H* dates.

Position 10, Wood (BP), West Virginia, represents the general intercontinental base area and base region, from whose *BR* average base records the date and period isophane constants of appendix table 7 were computed.

EXAMPLE 2.—*Equivalent isophanes and equivalent latitudes*

pno	Positions		Equivalents		Positions		Equivalents	
	pi	*pa*	*le*	*ei*	*pl*	*pa*	*le*	*el*
1	43.25	100	0.25	43.50	48.00	100	0.25	48.25
2	43.00	1,800	4.50	47.50	47.00	1,800	4.50	51.50
3	43.00	2,400	6.00	49.00	46.25	2,400	6.00	52.25
4	43.25	3,900	9.75	53.00	45.50	3,900	9.75	55.25
5	43.50	4,600	11.50	55.00	44.25	4,600	11.50	55.75
6	43.25	1,800	4.50	47.75	43.25	1,800	4.50	47.75
7	43.00	1,400	3.50	46.50	42.50	1,400	3.50	46.00
8	43.00	1,000	2.50	45.50	42.00	1,000	2.50	44.50
9	43.25	700	1.75	45.00	41.00	700	1.75	42.75
10	43.00	600	1.50	44.50	39.25	600	1.50	40.75
11	43.00	2,000	5.00	48.00	39.00	2,000	5.00	44.00
12	43.00	400	1.00	44.00	38.50	400	1.00	39.50
13	43.00	100	.25	43.25	38.00	100	.25	38.25

Example 2 shows how the equivalent isophane (*ei*) and equivalent latitude (*el*) is determined from *pi*, *pl*, and *pa* of the positions in example 1 (see explanation of symbols under record card A). This makes the *ei* and *el* available for the next procedure to determine the variations of the date and period records of example 1 from the isophane and latitude requirements for each position, as in examples 3, 3a, and 4.

EXAMPLE 3.—*Equivalent and record isophanes, with variations in latitude equivalents*

pno	*ei*	*S*		*H*		*P*		Zonal type	
		ri	*lev*	*ri*	*lev*	*ri*	*lev*	*Ma*	*Mi*
1	43.50	43.25	−0.25	58.50	+15.00	50.75	+7.25	II	+3
2	47.50	47.25	−.25	50.25	+2.75	48.75	+1.25		−.3
3	49.00	48.25	−.75	50.00	+1.00	49.00	.00		.3
4	53.00	48.25	−4.75	48.75	−4.25	48.50	−4.50		−.3
5	55.00	46.50	−8.50	48.75	−6.25	47.50	−7.50		+4
6	47.75	48.75	+1.00	46.50	−1.25	47.50	−.25		+4
7	46.50	47.75	+1.25	46.50	.00	47.00	+.50		+.4
8	45.50	48.75	+3.25	47.50	+2.00	48.00	+2.50		−3+4
9	45.00	48.00	+3.00	46.50	+1.50	47.25	+2.25		+4
10	44.50	44.50	.00	44.50	.00	44.50	.00		.4
11	48.00	44.00	−4.00	45.75	−2.25	44.75	−3.25		.4
12	44.00	41.25	−2.75	43.75	−.25	42.50	−1.50		+5
13	43.25	38.00	−5.25	43.25	.00	40.50	−2.75		−.5
Average			−1.38		+.62		−.46		−.40

EXAMPLE 3a.—*Variations in days from equivalent isophane constants of table 7*

pno	*S*				*H*				*P*				
	pc	*pr*	*dv*	*zt*	*pc*	*pr*	*dv*	*zt*	*pc*	*pr*	*dv*	±	*zt*
1	276	277	+1	II −4	170	230	+60	II .1	259	318	+59	−1	II +3
2	260	261	+1	+4	186	197	+11	+.3	291	301	+10	0	−.3
3	254	257	+3	−3	192	196	+4	+.3	303	304	+1	−1	.3
4	238	257	+19	−3	208	191	−17	−.3	335	299	−36	0	−.3
5	230	264	+34	+.4	216	191	−25	−.3	351	292	−59	+1	+4
6	259	255	−4	−.3	187	182	−5	+.4	293	292	−1	+1	+4
7	264	259	−5	+4	182	182	0	+.4	283	288	+5	−1	+.4
8	268	255	−13	−.3	178	186	+8	+4	275	296	+21	−1	−3+4
9	270	258	−12	−3+4	176	182	+6	+.4	271	289	+18	0	+4
10	272	272	0	.4	174	174	0	.4	267	267	0	0	.4
11	258	274	+16	−.4	188	179	−9	.4	295	270	−25	+1	.4
12	274	285	+11	.5	172	171	−1	−.4	263	251	−12	0	+5
13	277	298	+21	+.6	169	169	0	−4	257	236	−21	+1	−.5
Average			+5.53				+2.46				−3.07		+1.64

Example 3 shows how the *lev* latitude equivalent variations are determined from the isophane constants of appendix table 7, in which *ei* gives the equivalent isophanes of example 2; *ri*, the record isophane represented by the *S*, *H*, and *P* records referred to their corresponding constants in table 7; and *lev*, the latitude equivalent variation of *ri* from *ei*, which is equivalent to the variation of the records from their constants (example 3*a*) for the equivalent isophane.

The object of finding the latitude equivalent variation in example 3 instead of the day variation in example 3*a*, is to facilitate the application of the variation in latitude degrees to the isophane-latitude chart, in a comparison of their relations to the isophane- and latitude-requirement constants for each position, as in figure 12, and for the average in figure 13.

Example 3*a* gives for the *ei* in example 3 the *pc* position year-date and period constants of table 7; *pr* the position records in example 1; *dv* the variation in days of *pr* from *pc*, in which plus signifies later date and longer period and minus signifies earlier date and shorter period. Plus (+) or minus (−) indicates that the *P dv* is plus or minus 1 day as compared with the *P lev* latitude equivalent variation in example 3, which multiplied by 8 days gives the equivalent in days; e. g., for position 1 the *lev* 7.25 × 8 days equals 58 days, which is 1 day less than the actual *dv* in example 3*a*, because the period record 318 referred to table 7 comes between *ri* 50.75 and 51.00 and therefore is not given in the *P* column, where the rate is 2 days per 0.25° isophane.

For the *S* and *H* constants in the table the rate is 1 day per 0.25° or 4 days per 1°; therefore the *lev* of example 3 multiplied by 4 days gives the *dv* day variation in example 3*a*, while the rate for the period is 2 days per 0.25° or 8 days per 1°, so that *P lev* multiplied by 8 days gives the equivalent day variation within a range of 1 day.

Under zonal types in example 3, *Ma* gives the major and *Mi* the minor types represented by the *P* record isophane in table 7; in example 3*a*, the *zt* is the zonal type represented by the record *S* and *H* dates and the *P* in the same table of constants.

EXAMPLE 4.—*Equivalent and record latitudes, with variations in latitude equivalents from isophane constants in table 7 relative to parallel 43 and meridian 100*

pno	*S*			*H*		*P*		Zonal type	
	el	*rl*	*lev*	*rl*	*lev*	*rl*	*lev*	*Ma*	*Mi*
1	48.25	43.25	−5.00	58.50	+10.25	50.75	+2.50	II	+3
2	51.50	47.25	−4.25	50.25	−1.25	48.75	−2.75		−.3
3	52.25	48.25	−4.00	50.00	−2.25	49.00	−3.25		.3
4	55.25	48.25	−7.00	48.75	−6.50	48.50	−6.75		−.3
5	55.75	46.50	−9.25	48.75	−7.00	47.50	−8.25		+4
6	47.75	48.75	+1.00	46.50	−1.25	47.50	+.25		+4
7	46.00	47.75	+1.75	46.50	+.50	47.00	+1.00		+4
8	44.50	48.75	+4.25	47.50	+3.00	48.00	+3.50		−3+4
9	42.75	48.00	+5.25	46.50	+3.75	47.25	+4.50		+4
10	40.75	44.50	+3.75	44.50	+3.75	44.50	+3.75		.4
11	44.00	44.00	.00	45.75	+1.75	44.75	+.75		.4
12	39.50	41.25	+1.75	43.75	+4.25	42.50	+3.00		+5
13	38.25	38.00	−.25	43.25	+5.00	40.50	+2.25		−.5
Average [1]			−.92		+1.07		.00		+.05

[1] The average variations relative to parallel 39.25° are *S* −4.67, *H* −2.67, and *P* −3.75 as shown in fig. 13.

Example 4 shows how the *lev* latitude variations are determined from the isophane constants of table 7, in which the *el* equivalent latitude referred to the table gives the latitude constant; the position record referred to the corresponding constant gives the *rl* record latitude; and the difference between *el* and *rl* gives the *lev* relative to the parallel of the same number as the position isophane, as represented in figure 12 by parallel 43. Average gives the general average variations from the latitude requirements of parallel 43 across the continent. It is to be recognized that this average includes minus variations west and plus east of the one hundredth meridian, while the averages are relative to the base meridian and thus are to be compared with the average variations from the base parallel.

Thus from any table of isophane constants the position isophane and position latitude constants are found by the equivalent isophane and equivalent latitude, and the position record referred to the corresponding constant in the table gives both the record isophane and record latitude which are always the same number for the same position. Then the difference between *ri* and *ei* will be the *lev* of *ri* from *ei*, and the difference between *rl* and *el* will be the *lev* of *rl* from *el*, always relative to the one hundredth meridian and the parallel and isophane of the same numerical designation.

Variations relative to the requirement constants for any given latitude and meridian east or west of the one hundredth may be computed by the difference between the position isophane and position latitude, plus or minus the latitude variation as determined by the process illustrated in example 4. Thus to find the variation from the base position latitude 39.25° relative to the base isophane 43 and base meridian 81.25°, take the difference (43.00−39.25°) 3.75°, which plus or minus the *S*, *H*, and *P* variations for positions 1 or 9 gives the same variations from the requirement constants for the base parallel and base meridian as shown in figure 12 and as follows:

	S			*H*			*P*		
	lev ex. 4	diff.	*bm* fig. 12	*lev* ex. 4	diff.	*bm* fig. 12	*lev* ex. 4	diff.	*bm* fig. 12
1	−5.00	+3.75	−8.75	+10.25	−3.75	+6.50	+2.50	−3.75	−1.25
9	+5.25	−3.75	+1.50	+3.75	+3.75	.00	+4.50	−3.75	+.75

This is a tedious process of finding the relative variations from the base parallel, and since the charted isophane variations (fig. 12) give at once by measurement the relative variations from any given parallel within the range of the base isophane, computations are unnecessary.

The zonal types of examples 3, 3*a*, and 4 are significant as indices to the relative influences of the local causation-factor complex during the short seeding and harvest periods and during the long period of growth between seeding and harvest.

Thus for position 1 (example 3*a*) the seeding zonal type is major II minor lower 4 (−4); the harvest type, II middle 1 (.1); and the period type, II upper 3 (+3). This indicates that the conditions at seeding time are equivalent to those characteristic of the midtemperate or Merriam's Upper Austral zone; those at harvest time, to those conditions characteristic of Merriam's Boreal zone; and those during the period of growth, to those characteristic of his Transition zone.

As shown in all examples which include the zones and zonal types in this and part 2, and in the detailed

discussion of the bioclimatic zones in part 2, the zone and zonal types represented by time, thermal, or distance records of a place serve as indices of fundamental importance to the bioclimatic features of any position or region for which records are available.

It is to be kept in mind that the minus signs for variations in examples 3 and 4 relate to lower and warmer latitudes and the plus signs to higher and colder *P* variations to each other, relative to the requirements of bioclimatic law, as represented by the base isophane 43 across the continent; and (2) the relation of the same variations to the requirements of astronomic law, as represented by the base parallel of latitude 39.25° and also by parallels 38 to 48 across the continent.

The principle and elements of this isophane-latitude chart are the same as those explained in figures 9 to 11,

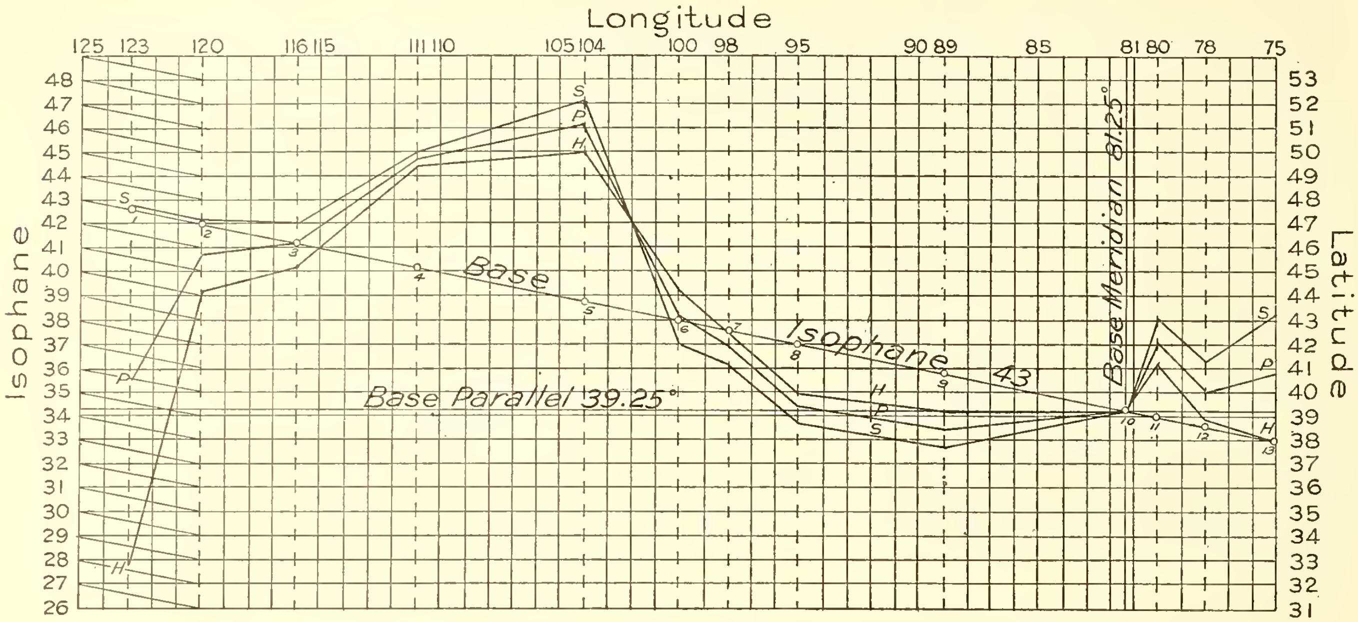

FIGURE 12.—Variations of winter wheat seeding and harvest dates and periods from isophane and latitude requirements.

ones; but these are reversed in the isophane-latitude chart (fig. 12), where *plus* signifies above the base isophane or latitude and warmer than the requirement constants, while *minus* signifies below and colder.

The averages of the position variations (for each subject) from the isophane requirements of bioclimatic law in examples 3 and 3*a*, and from the parallel of latitude requirements of astronomic law in example 4, for all 13 with the addition of broken lines for the position meridians, the position numbers on the base isophane, and the variation points on the position meridians with connecting lines represent the extent and trend of the variations from the isophane and latitude requirements.

Figure 13 represents the variations of the *S*, *H*, and *P* average variations in example 3 from the isophane requirements, and in example 4 from the latitude

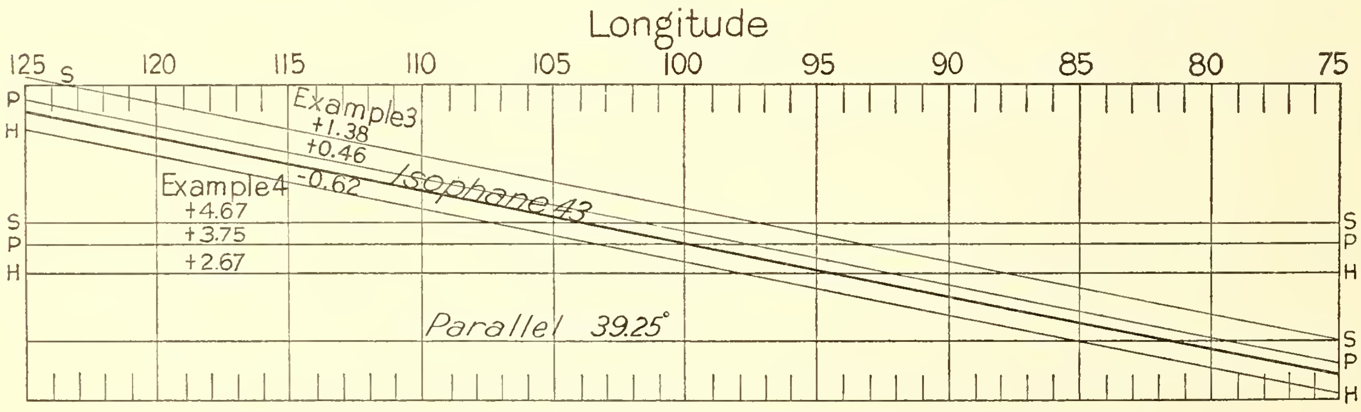

FIGURE 13.—Average winter wheat seeding, harvest, and period variations from isophane and latitude requirements.

county positions across the continent show that the general average for all 3 comes much nearer to the latitude requirements as represented by parallel 43. In example 4 and figure 13, the variations are greater from the base parallel 39.25° than from isophane 43.

Figure 12 shows, by the isophane-variation points and lines, for each of the 13 positions of example 1, and the *S*, *H*, and *P* variations of example 3 with the *plus and minus signs reversed:* (1) the relations of the *S*, *H*, and requirements, as measured from parallel 43 on the one hundredth meridian, and from the base parallel 39.25° on the base meridian 81.25°.

In figure 12 the points on the position meridians represent the *lev* of example 3 from the isophane requirements as measured in degrees of latitude from the base isophane, with the plus and minus signs of example 3 reversed, thus conforming to the principle of the sea-level isotherm.

The lines connecting the variation points on the position meridians are designated as *variation lines* and serve simply to indicate the trend of the variations from the requirements of bioclimatic and astronomic law across the continents.

In this principle and method of the charted variations of records from isophane and latitude constants, the *S*, *H*, and *P* variation lines represent, for each, the variations from both the isophane and latitude requirement constants for the given positions, because when the base isophane and base latitude lines are drawn through the intercontinental base the variation lines represent the coordinate relations not only between those variations from the *position isophane* and *position latitude* but also between variations from all positions regardless of difference in their numerical designation.

It is to be kept in mind, therefore, (1) that a base isophane and a base parallel through a given base position of any isophane-latitude chart (as in figs. 9 to 12) will represent the isophane and latitude variations of any position, simply because *any isophane represents the requirement of bioclimatic law and any parallel that of astronomic law;* and (2) that *the variation of a position record isophane from the equivalent position isophane or equivalent position latitude is in each case equivalent to the same variation from the charted base isophane and base parallel.*

Thus an isophane and parallel of latitude drawn from any given base meridian will serve as a line of reference for the relative variations from the isophane and latitude requirements for any and all isophane, latitude, and altitude positions.

In comparative bioclimatics the significance of this principle will be apparent when it is recognized that *it is not necessary to determine the variations from the latitude-requirement constants of a separate table, because when the variations from the isophane requirements are charted they will always represent the variations from the corresponding latitude-position constants, not only relative to the given base parallel, but to any parallel of the chart within the latitude range of the given base isophane,* as in figure 12 between latitude 38 on the east to latitude 48 on the west coast. In other words, the *S*, *H*, and *P* latitude variations from the latitude requirements of a given latitude position, as for position 2, latitude 47, longitude 120, are as given in example 4 relative to parallel 43; while for the same subjects and position the variations from the isophane requirements for the same position are as given in example 3, with reversed plus and minus signs as follows:

Example 4.	*S*+4. 25	*H*+1. 25	*P*+2. 75	*lv* latitude variation.
Example 3.	*S*+0. 25	*H*−2. 75	*P*−1. 25	*iv* isophane variation.
	4. 00	4. 00	4. 00	differences.

Thus the difference between the latitude and isophane variations is the same as the difference between the *pl* position latitude 47 and *pi* position isophane 43, and the same as between latitude 47 and latitude 43. This shows that the *lv* is the difference between the *pl* and *pi* plus the *iv;* as *pl* − *pi* (equals *diff.*) + *iv* equals *lv.* So that as measured on the chart the variation from the latitude requirements is represented by latitude 43 just as the variation from the isophane is represented by isophane 43. Thus with the isophane variations charted, the *iv* as determined in example 3 is measured from the given base isophane, and the corresponding *lv* from the base or any parallel is measured from the parallel to the point or line of the isophane variation.

Therefore to determine on the chart the position latitude variation, the process is simply to measure the distance on the position meridian between the position isophane variation and the base parallel 39.25°. Under the same principle the distance between the isophane variation and any other parallel will be the corresponding latitude variation relative to the given parallel and position meridian.

Computing the Latitude Variations

While the chart method provides for finding the relative latitude variations by the simple process of measurement, the latitude variation for a given position or of any number of positions can be computed by the rule that *the difference between the position latitude and any given parallel, plus or minus the isophane variation of the same position will give the latitude variation relative to the given parallel.*

It is significant that the principle of the isophane-latitude chart is available for universal application to show, by variation lines from a given base isophane, their relations to the variations from the position isophane constants or any other isophane across a region or continent, and at the same time their relations to the variations from the position latitude constant relative to any given parallel of latitude, so that the chart serves as a basis of direct comparison of variations from the requirements of bioclimatic and astronomic laws of lines of equal bioclimatic phenomena across a continent.

By reference to figure 12 it will be seen that the trend of the variation lines is more nearly with that of the isophane than with the base parallel of latitude; while figure 13 shows that the lines representing the average *S*, *H*, and *P* variations from the isophane requirements, as represented by the base isophane, come very much closer to it than they do to the latitude requirements, as represented by the base parallel. This test by the given record time subjects and variation lines serves to show, therefore, that the isophane lines of equal phenomena across North America are truly more nearly in accordance with bioclimatic than they are with astronomic law.

A number of significant features are brought out by the principle of comparing the departures from the requirements of the two laws, and especially in their indication (fig. 12) of the modifying influences of the western coast, western mountain, interior basin, eastern mountain, and eastern coast regions across the continent. Thus, as interpreted in terms of relatively warmer or colder influences from the position constants, and taking the period as the representative index to the trend of the departures due to the effect of major physiographic causes, the period line plainly indicates that at position 1 on meridian 123 a decidedly colder condition prevails relative to the isophane requirements. The seeding date is near normal, and the late date for harvest shows an extreme cold departure with an intermediate but cold departure for the period. In the latitude requirements of this position relative to the base parallel 39.25°, the period departure is near normal with an extreme warmer departure for seeding and an extreme colder departure for harvest. The period variation line from west to east represents a norm from the isophane at position 3 in Idaho, rises to an extreme warm variation over the Rocky Mountain region to position 5 in Wyoming, and then drops rapidly to near normal at position 6 in South Dakota on the one hundredth

meridian; from here it extends in a broad cold curve below the isophane across the Mississippi Basin to the intercontinental base position 10, then rises to a maximum warm in the Allegheny Mountains, and remains warm to the Atlantic coast at position 13.

These significant features are represented by the relative distance of the *S*, *H*, and *P* variations from the base isophane as indicating the relative intensity of the influences of the major and minor causation-factor complex. Thus from west to east are found such distinctive regions of marked and different influence as the western coast, western coastal mountains, Cascade and Rocky Mountains, western plains, interior Great Basin, eastern mountains, and the eastern coast with minor transition regions coming between, each with its characteristic coastal, mountain, interior-plains, lowland, and transition types of climate.

There are interesting and significant differences in the relations of the *S* and *H* to the *P* variations, as *S* above and *H* below *P* (SPH) at positions 1 to 5, inclusive, and the reverse *H* above and *S* below *P* (HPS) at positions 6 to 9 inclusive, thus indicating the influence of different major types of climate in general agreement with the *a*, *w*, and *c* relations in figure 16, in which positions 1 to 4, inclusive, have *c* above and *w* below the *a* variation representing a major coastal or mountain type of climate, while positions 6 to 9, inclusive, have *w* above and *c* below the *a* variation representing a major continental type of climate. There is, however, a noticeable difference at position 5 in the relations of the *SPH* of figure 12 and the *wac* of figure 16.

The influence of these regions on the dates of seeding and harvest and length of periods relative to the isophane requirements represented by the base isophane are indicated by the variations in example 3a and the *SPH* and *HPS* types of variations in figure 12. Here position 1 represents an extreme west-coast *SPH* type, with near-normal seeding and extremely late harvest dates and a longer period; position 2, a west-coast plain *SPH* type, with near-normal seeding and late harvest dates and a moderately long period; position 3, a transition *SPH* type, with late seeding and harvest dates and near normal period; positions 4 and 5, a western high plains and mountain extreme *SPH* type, with very late seeding and early harvest dates and much shorter periods; positions 6 to 9, an interior basin *HPS* type, with all seeding dates early, 6 with harvest date early, 7 normal, and 8 and 9 late, with the period for 6 near normal, and for 7, 8, and 9 longer; position 10, the intercontinental base, an eastern transition region between *SPH* and *HPS*, with a *SHP* normal seeding and harvest dates and period type; and finally, positions 11 to 13 represent an *SPH* eastern-mountain and east-coast type with much later seeding and earlier-to-normal harvest dates and much shorter periods, than the isophane requirements.

One of the more significant features of the variation lines is in their indication that *the base area does in fact represent a normal* or intermediate climatic type, in that it comes in the transition between the coastal and mountain to the east and the continental to the west, and therefore serves the purpose of a normal continental and intercontinental base for the interpretation of coordinate relations.

INTERPRETATION OF BIOCLIMATIC ZONAL TYPES

In addition to the many significant features of the tabulated and charted variations of record time subjects from their position requirement constants, as given in examples 3 and 4 and illustrated by the chart method, one of the most important is in the indication of the major and minor bioclimatic zonal types represented by the record or record isophane of each position.

Thus it is shown that almost the entire isophane and equivalent altitude zonal range of winter wheat culture in North America is represented by the period records in the list of counties and average altitudes of their record positions from minor upper 3 (+3) of major II for position 1 to lower middle 5 (—.5) for position 13. (For further discussion of this subject see pp. 47–49.)

One of the conclusions to be drawn from these first test examples, based on the time subjects of winter wheat seeding and harvest dates and periods in days, is that the relatively few record areas, involving as they do a rather wide range of error, cannot be anything more than preliminary evidence in support of the bioclimatic law. Nevertheless, it will be noted that, in comparing the results of these tests with the tests by thermal and distance subjects which follow, they come close enough to the facts to support the bioclimatic law and the principles and methods of application, and thus serve as a reliable basis for preliminary interpretation of bioclimatic phenomena for specific places and regions.

KILLING FROSTS AND FROSTLESS PERIODS

The dates of killing frost in the spring and autumn, and the frostless period in days are given on position thermal record cards like sample A, under the symbols *L* for the average date of latest killing frost in spring, *E* for the average date of earliest killing frost in autumn, and *P* for the period in days between *L* and *E*.

For comparison of the variations of record frost dates and periods from the requirement constants with those of winter wheat seeding and harvest dates and periods, and with variations of thermal records, the following example is made up from the record card catalogue, based on averages for one or more positions in 1°×1° isophane-longitude quadrants to represent the same local regions as those represented in example 1.

EXAMPLE 5.—*List of quadrants with variations for record frost dates and periods, and with zonal types represented by period records*

Quad. no.	No. of posit.	*pi*	*plo*	*pa*	*L*	*E*	*P*	Zonal type	
					lev	*lev*	*lev*	*Ma*	*Mi*
1	1	43	123	0	−1.00	−0.75	−1.00	II	+.5
2	5	43	120	1,700	−4.75	−.50	−2.00		.4
3	3	43	116	1,500	−2.75	−3.00	−3.00		−.4
4	5	43	111	4,400	−4.50	−3.00	−3.75		+3
5	5	43	104	4,800	−3.50	−4.25	−3.75		−2+3
6	2	43	100	2,500	−1.75	−2.00	−1.75		+4
7	2	43	98	1,500	+.25	+1.75	+1.00		+4
8	1	43	95	1,200	+2.25	+.75	+1.50		+4
9	5	43	89	700	.00	−.25	.00		.4
10	9	43	81	600	.00	.00	.00		.4
11	9	43	80	900	+1.25	−.25	+.75		+.4
12	7	43	78	800	−1.50	−1.00	−1.25		.4
13	6	43	75	0	−.50	−1.25	−.75		+5
Average					−1.26	−1.05	−1.07		−1.12

The elements of example 5 include *quad. no.* quadrant number to correspond with the county numbers in example 1; *no. of posit.* number of record positions with frost data coming within each quadrant; *pi* the position isophane 43 of the lower border of the 1°×1° isophane-longitude quadrant; *plo* the position longitude of the east border of the quadrant; *pa* the average altitude of the record positions; *L lev* the average of the latitude equivalent variations of the record isophanes from the equivalent isophanes for the latest killing frost in

spring; *E lev* the average latitude equivalent variation for the earliest killing frost in autumn; and *P lev* the average latitude equivalent variation for the frostless period. All of these variations are determined by referring the *L*, *E*, and *P* records to appendix table 6 to find the record isophane represented by the corresponding constant and its variation from the equivalent isophane. Under *zonal type*, *Ma* gives the major and *Mi* the minor type represented in the zonal scale of table 6 by the average period record and record isophane.

In a comparison of the variations of this example with those of example 3, it is to be kept in mind that the only subjects that are comparable as to time, in that they both relate to the autumn season, are seeding dates in example 3 and earliest frost dates in autumn in this example. These variations are not, however, directly comparable, because so many different elements are involved, including (1) the different number and different geographic position of the record positions, (2) some difference in the area represented by the county in one and the quadrant in the other, and (3) the fact that the frost date may be influenced by a local cold spell limited to a single night, while the seeding date is influenced by the general weather conditions during a period of 10 or more days.

There is little or no apparent relation between the variations of the harvest dates and spring frost, or between the wheat period of the greater part of the year and the frostless period of the warm period or growing season. For these reasons there are no close relations between the zonal types represented by the wheat periods and those represented by the frostless periods.

When, however, the frost variations are charted, as in figure 14, there is seen a striking relation between the general trend of the wheat and frost variations from their requirement constants, except toward or on the western coast.

In comparing the variation lines of this chart with those of figure 12 with its full explanation, it will be noted that, while there are some differences, there is a remarkable agreement in the general trend of the period line relative to the isophane requirements, especially between positions 3 and 6, where it is distinctly above and warmer; while between 7 and 8 it is below and colder than the isophane requirements. The notable differences are (1) at position 11, where the *L* and *P* lines are below in this figure instead of above as in figure 12; at position 9, where they are with, or close to, the isophane; and from 1 to 3, where they are all above the isophane and far above the latitude requirements of parallels 43° and 39.25°.

There is also a difference in the relations of the *L* and *E* lines to *P* line across the regions of different climatic types. For position 1 they are all close together and near the isophane, while for position 2 *L* is above and *E* below *P*, indicating a warm early spring and cool early autumn relative to *P*, but all are warmer than the isophane requirements. At position 3 the *L*, *E*, and *P* lines nearly join; at position 4 they represent the same but less intense *LPE* (*L* warmer and *E* colder than *P*) type as at 2; at position 5 they revert to a moderate *EPL* (*E* warmer and *L* colder than *P*) type, nearly joining again at position 6 and returning to the *LPE* type at 7, and back again to the *EPL* type at position 8; then, joining between positions 9 and 10, they change to the *EPL* type at 11, then back again to the *LPE* type at 12, and again to the *EPL* type at position 13. Thus the *LPE* type is, in general, representative of the western coast and western mountain type and of the eastern mountain type, while the *EPL* type is suggestive of the continental type at 8 and 11, and of the eastern coast type at position 13, with an *LPE* exception at position 7, and an *EPL* exception to the mountain type at position 5.

In comparing figures 12 and 14 it will be noted that the variation lines for the frost data agree even more closely in their general trend with the isophane than do those of the wheat data, and thus furnish additional support for the bioclimatic law.

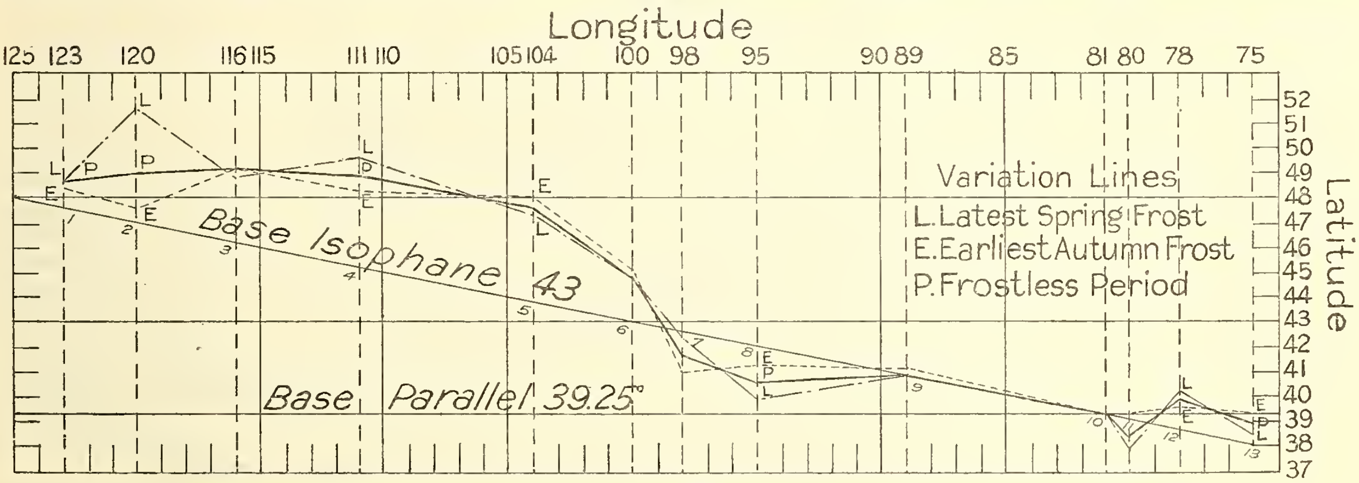

FIGURE 14.—Variations of spring and autumn frost dates and frostless period from isophane and latitude requirements.

DATES FOR THE BEGINNING OF THE THERMAL SEASONS

Under this subject the record dates for the beginning of spring, summer, autumn, and winter, and the period in days for the *warm period* are determined by the thermal indices (see appendix schedule 2) and are taken as the subjects by which the record isophanes are determined in appendix table 9. The variations from the requirement constants are determined in the usual way by finding the difference between the equivalent and record isophanes.

In this test single geographic positions of meteorological stations are selected on or near the base isophane 43 to represent the same regions as in the preceding examples.

EXAMPLE 6.—*List of positions and record dates and periods for the beginning of the seasons and length of the warm period*

Position			Geographic position				Year dates				Days
pno	Station	State	*pi*	*plo*	*pa*	*ei*	*Sp*	*Su*	*Au*	*Wi*	*P*
1	Port Angeles	Washington	43.25	123	0	43.25	60	182	244	311	251
2	Cle Eluim	do	43.00	120	1,900	47.75	105	196	227	296	191
3	Moscow	Idaho	43.25	116	2,700	50.00	105	188	235	305	200
4	Canyon Ferry	Montana	43.25	111	3,700	52.50	105	182	235	296	191
5	Sundance	Wyoming	43.50	104	4,800	55.50	121	188	227	288	167
6	Rosebud	South Dakota	43.00	100	2,600	49.50	97	158	250	305	208
7	Lynch	Nebraska	43.00	98	1,400	46.50	97	158	258	305	208
8	Washta	Iowa	43.25	95	1,200	46.25	97	158	258	305	208
9	Henry	Illinois	43.25	89	500	44.50	91	152	266	311	220
10	General Base Area.	West Virginia and Ohio.	43.00	81	600	44.50	84	152	266	314	230
11	Philippi	West Virginia	43.00	80	1,100	45.75	82	158	258	319	237
12	Stephens City	Virginia	43.25	78	700	45.00	74	143	266	319	245
13	Princess Anne	Maryland	43.00	75	0	43.00	74	143	274	335	261

In example 6 *pno* gives the position numbers of the stations and states. Under year dates, the dates as determined from the normal monthly means by the thermal indices are for the beginning of *Sp* spring, *Su* summer, *Au* autumn, and *Wi* winter, while days *P* gives the number of days in the warm period between the date for the beginning of spring and the date for the beginning of winter. (For method of procedure in finding the dates and periods see explanation in appendix schedule 2.)

The principle and elements of figure 15 are the same as in figures 12 and 14. In comparing the *Sp* to *P* variation lines of this chart with those of figures 12 and 14, it is to be kept in mind that we are here representing different dates and periods, based on a schedule of thermal indices (appendix schedule 2) to serve as indices to the general average or monthly mean temperatures to characterize the average dates of the beginning of the seasons at any given record position. Such dates are equivalent to records which, when referred to appendix table 9, give the record isophane from which the variations and zonal types are determined.

There is a broad general agreement in the period variations in this chart with the *P* variations in figs. 12 and 14 except at position 1 in figure 12, and especially is there a marked general agreement in the trend of the variation lines and their relations to the major climatic types as represented by the western coast, western basin, western great mountain plateau, interior Great Basin, eastern mountain, and eastern coast regions across North America, as related to the isophane and latitude requirements.

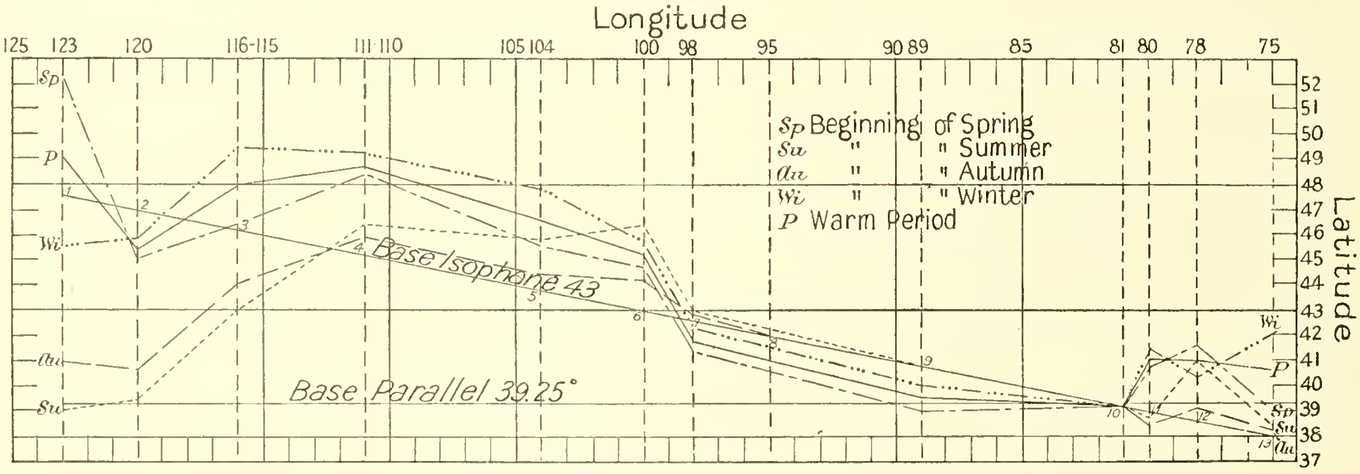

FIGURE 15.—Variations of the beginning of the thermal seasons and length of the warm period from isophane and latitude requirements.

EXAMPLE 7.—*Latitude equivalent variations and zonal types for positions and subjects in example 6*

pno	Latitude equivalent variations					Zonal types				
	Sp	*Su*	*Au*	*Wi*	*P*	*Sp*	*Su*	*Au*	*Wi*	*P*
1	−4.75	+8.50	+6.50	+2.00	−1.50	II +.6	II −2	II .3	II .4	II .5
2	+2.00	+7.50	+6.25	+1.25	+1.75	.3	+.2	.2	.3	.3
3	−.25	+3.25	+2.25	−3.25	−1.75	.3	.2	−.2	+.4	−3
4	−2.75	−.75	−.25	−3.50	−3.00	.3	−2	−.2	.3	.3
5	−2.00	−2.25	−1.50	−4.25	−3.00	.2	.2	.2	−2	−.2
6	−1.75	−3.50	−1.25	−2.75	−2.25	+4	.4	−3	+.4	+4
7	+1.25	−.50	−.25	+.25	+.75	+4	.4	.4	+.4	+4
8	+1.50	−.25	.00	+.50	+1.00	+4	.4	.4	+.4	+4
9	+1.75	.00	.00	+.75	+1.25	.4	.4	.4	.4	.4
10	.00	.00	.00	.00	.00	.4	.4	.4	.4	.4
11	−1.75	+.25	+.50	−2.50	−2.00	−.4	.4	.4	−4	−.4
12	−3.00	−2.50	−.50	−1.75	−2.50	+.5	+5	.4	−4	+5
13	−1.00	−.50	−.25	−4.00	−2.50	+.5	+5	+5	+6	−.5

Example 7 gives the *pno* of example 6, with the latitude equivalent variations of the record isophane by table 9 from the equivalent isophane for the position constants of the subjects represented by the symbols *Sp* to *P*, as explained under the preceding example.

The positions of the variation lines above the isophane signify earlier dates and warmer than the requirement constants for spring and summer and longer and warmer growing season, and those below the isophane for the same subjects signify later dates and colder and shorter periods. For autumn and winter the positions and lines above the isophane signify later dates and warmer, while those below signify earlier dates and colder than the requirement for the given positions.

SIGNIFICANT FEATURES

Among the significant features brought out in this chart of variations of the beginning of the seasons and length of the warm period relative to the major climatic types, and to the variations of the wheat and frost data are: (1) The general trend of the variation lines corresponds with the general trend of those in figures 12 and 14; (2) in this respect the spring, winter, and warm period between spring and winter, are of special interest in indicating that the eastern mountain and coast regions relative to their constants are warmer with longer periods east of the base meridian 81; (3) the Great Basin is relatively cooler with spring late and winter early; (4) there is a transition normal type between meridians 98 and 100 as shown in the other figures; (5) the Great Plains and western mountains have

a relatively early beginning of spring type and later beginning of winter type, with longer period between about meridians 99 and 116; (6) there is another transition normal type at about meridian 120, with a change to a distinctive western coast type at meridian 123, where spring begins much earlier, winter earlier, autumn earlier, and summer very much later, with a slightly longer period; and (7) the summer and autumn lines follow the same broad northwest trend from the base to about meridian 111, with both practically normal to the isophane between meridians 81 and 97 and between 112 and 113, and both fall to or near the latitude requirements between meridians 120 and 123.

The most significant feature of this test is the fact that *a single position within a given major climatic or region type will, as a rule, reflect and indicate the same modifying influence as does the average of a number of stations by the quadrant method.* This represents one of the outstanding principles in applied bioclimatics: *Bioclimatic conditions may be interpreted for a specific geographic record position from its records and variations, and for an area, region, or physiographic type by the trend and relations of the variations for all positions relative to the isophane and latitude requirements across the area.*

TEST EXAMPLES BY TEMPERATURE RECORDS

The primary objects of tests by temperature records are the same as those by time subjects, in that by the variable and constant principles the coordinate relations between the requirement constants of bioclimatic and astronomic law are found, and it is determined whether or not the variation of the record variable from its position isophane constant serves as a reliable index to the interpretation of bioclimatic phenomena.

The principle and method are the same, but there is a difference in tests by thermal records in that the record isophane is modified for position altitudes at or above 2,000 feet, as in record thermal card C.

Example of thermal record card C. Modifications for altitudes at or above 2,000 feet

Buffalo, Wyo.: *pi* 43.00, *plo* 106. N. A., U. S.
pl 44.25°, *plo* 106, *pa* 4,600 ft., *le* 11.50, *me* 2.75, *ei* 54.50. ZC II.2

Years	Subject thermal	Sym.	Rec. °F.	App. tab.	*ri*	*me*	*mri*	Variations *lev*	Variations *ed*	Variations *eft*	*Sym.*
17	Annual mean	*a*	44.4	3	51.50	−2.75	48.75	−5.75	+23	2,000	*az* —.3
17	Warmest monthly mean.	*w*	68.0	3	51.00	−2.75	48.25	−6.25	+25	2,500	*wt* −3
17	Coldest monthly mean.	*c*	22.7	3	50.50	−2.75	47.75	−6.75	+27	2,700	*ct* +4

The principle and elements of thermal record card C are the same as those of card A, except that *me* gives the modified equivalent of *le* to represent a relatively warmer effective influence with higher altitudes [12] expressed in the *mri* modified record isophane, as *le* divided by 4 equals *me*, which plus *ri* equals *mri* (*le* is divided by 4 because it represents 0.25°). Thus the variation of *mri* from *ei* gives a more nearly correct variation in equivalent latitude of the thermal record from its position constant and a more correct interpretation of the zone or zonal types represented by the position altitude.

Example table of altitudes in feet and their latitude equivalents (le) and modified equivalents (me)

Altitude	*le*	*me*	Altitude	*le*	*me*
20,000	50.00	12.50	8,400	21.00	5.25
19,600	49.00	12.25	8,000	20.00	5.00
19,200	48.00	12.00	7,600	19.00	4.75
18,800	47.00	11.75	7,200	18.00	4.50
18,400	46.00	11.50	6,800	17.00	4.25
18,000	45.00	11.25	6,400	16.00	4.00
17,600	44.00	11.00	6,000	15.00	3.75
17,200	43.00	10.75	5,600	14.00	3.50
16,800	42.00	10.50	5,200	13.00	3.25
16,400	41.00	10.25	4,800	12.00	3.00
16,000	40.00	10.00	4,400	11.00	2.75
15,600	39.00	9.75	4,000	10.00	2.50
15,200	38.00	9.50	3,600	9.00	2.25
14,800	37.00	9.25	3,200	8.00	2.00
14,400	36.00	9.00	2,800	7.00	1.75
14,000	35.00	8.75	2,400	6.00	1.50
13,600	34.00	8.50	2,000	5.00	1.25
13,200	33.00	8.25	1,800	4.50	-------
12,800	32.00	8.00	1,600	4.00	-------
12,400	31.00	7.75	1,400	3.50	-------
12,000	30.00	7.50	1,200	3.00	-------
11,600	29.00	7.25	1,000	2.50	-------
11,200	28.00	7.00	800	2.00	-------
10,800	27.00	6.75	600	1.50	-------
10,400	26.00	6.50	400	1.00	-------
10,000	25.00	6.25	300	.75	-------
9,600	24.00	6.00	200	.50	-------
9,200	23.00	5.75	100	.25	-------
8,800	22.00	5.50	0	.00	-------

The example table given above serves as a convenient reference to find the *le* to any *pa* to apply to *pi* in finding the *ei* to the *pa* of a record or nonrecord position, and also to find the *me* to modify the *ri* or its equivalent *iex.* Formulae; *pa* ÷ 400 equals *le*, *le* ÷ 4 equals *me*; *ri* − *me* equals *mri* north; *ri* + *me* equals *mri* south. The *le* is 0.25° for each 100 feet, so that *le* can be readily found for any position altitude within 100 feet. In a like manner the *me* (which is *le* divided by 4, or *pa* divided by 16 to modify the altitude) is 0.25° for each 400 feet as the minimum requirement, because *me* for less than 400 feet is not recognizable in its modified effect.

As applied to the positions in example 8 the *le* and *me* for the position altitudes are as follows:

	Positions 1	2	3	4	5	6	7	8	9	10	11	12	13
pa	200	1,700	1,500	4,400	4,800	2,500	1,600	1,400	700	700	900	800	0
le (plus)	0.50	4.25	3.75	11.00	12.00	6.25	4.00	3.50	1.75	1.75	2.25	2.00	.00
me (minus)	-----	-----	-----	2.75	3.00	1.50	-----	-----	-----	-----	-----	-----	-----

It will be noted that for positions 2, 3, 6, 9, 10, and 11 the position altitudes differ 100 feet from the nearest altitude in the table, in which cases one interpolates to get the required *le*. Also for position 6 at 2,500 feet the *me* is 1.50, because a position of less than 0.25 is not recognized. Thus to find the *le* for positions coming between the given altitudes in the tables, add 0.25 for each additional 100 feet; and to find the corresponding *me* for position altitudes above 2,000 feet, utilize that in the table coming nearest to the position altitude, e. g., 1.50 for 2,400 to 2,600 feet and 1.75 for 2,700 to 2,800 feet.

In the following application of the latitude equivalent variations for the *a*, *w*, and *c* subjects, the given variations include modifications for positions at or above 2,000 feet, because the variations are taken directly from the index cards for the positions, or as averages computed from record cards for more than one position within a 1°×1° quadrant.

[12] In connection with the development of the record card index for record positions in the Northern and Southern Hemispheres, it was discovered that the increase effective influence for the Northern Hemisphere above about isophanes 15–25 north is reversed for the central tropical regions and all of the continents of the Southern Hemisphere, in that the effective influence relative to recorded temperature *decreases* with altitudes at and above 2,000 feet; so that here *ri* plus *me* is required to find the correct variation of *mri* from *ei* and the zone.

EXAMPLE 8.—*List of quadrants with average altitudes, thermal variations, zones and zonal types, and normal annual precipitation*

Quad. no.	No. of posit.	*pi*	*plo*	*pa*	*a*		*w*	*c*	Zonal type		A. Precip.	
					lev	Zone	*lev*	*lev*	*w*	*c*	No.	Rec.
												In.
1	4	43	123	200	+4.50	II −.3	+15.25	−3.00	II +.1	II −.5	2	22.82
2	5	43	120	1,700	+.50	−3+4	+.75	+.50	−.3	−3	5	13.98
3	3	43	116	1,500	−.50	+.4	+.75	−1.50	+4	.4	3	21.15
4	5	43	111	4,400	−4.75	.3	−4.00	−6.25	+.3	−3	5	13.55
5	5	43	104	4,800	−4.25	+3	−6.50	−3.25	−3	−2	5	16.91
6	2	43	100	2,500	−1.50	−3+4	−6.25	+1.25	−4	+3	2	18.66
7	3	43	98	1,600	+2.00	.3	−2.00	+5.50	.4	−.2	3	23.55
8	3	43	95	1,400	+2.25	.3	−.75	+7.50	.4	.2	3	30.09
9	6	43	89	700	+2.25	+4	−.50	+5.75	.4	−2+3	6	33.31
10	9	43	81	700	.00	.4	.00	.00	.4	.4	9	41.23
11	9	43	80	900	−.50	.4	+.50	−.75	.4	.4	9	43.60
12	8	43	78	800	−1.00	.4	−1.00	−1.00	.4	.4	9	36.83
13	8	43	75	0	−.75	+5	−.75	−1.00	+5	+5	8	43.00
Average					−.13		−.34	+.28				27.59

It is to be kept in mind that, in comparing the thermal variations for a quadrant and the wheat dates and period variations for a corresponding county, so many minor differences are involved, e. g., in the size of the area and in the location and number of different thermal and time record positions with their different altitudes, that a close agreement in the variations is not to be expected; but there is in fact a remarkably close agreement between the general trend of the *S*, *H*, and *P* variation lines in figure 12 and that of the *a*, *w*, and *c* variation lines in figure 16.

Figure 16 gives the variations in example 8 to show the relative positions of the plus warmer variations above and the minus colder variations below the base isophane, as connected by variation lines which show the general trend of the departure from the isophane requirements of bioclimatic law and also from the latitude requirements of astronomic law.

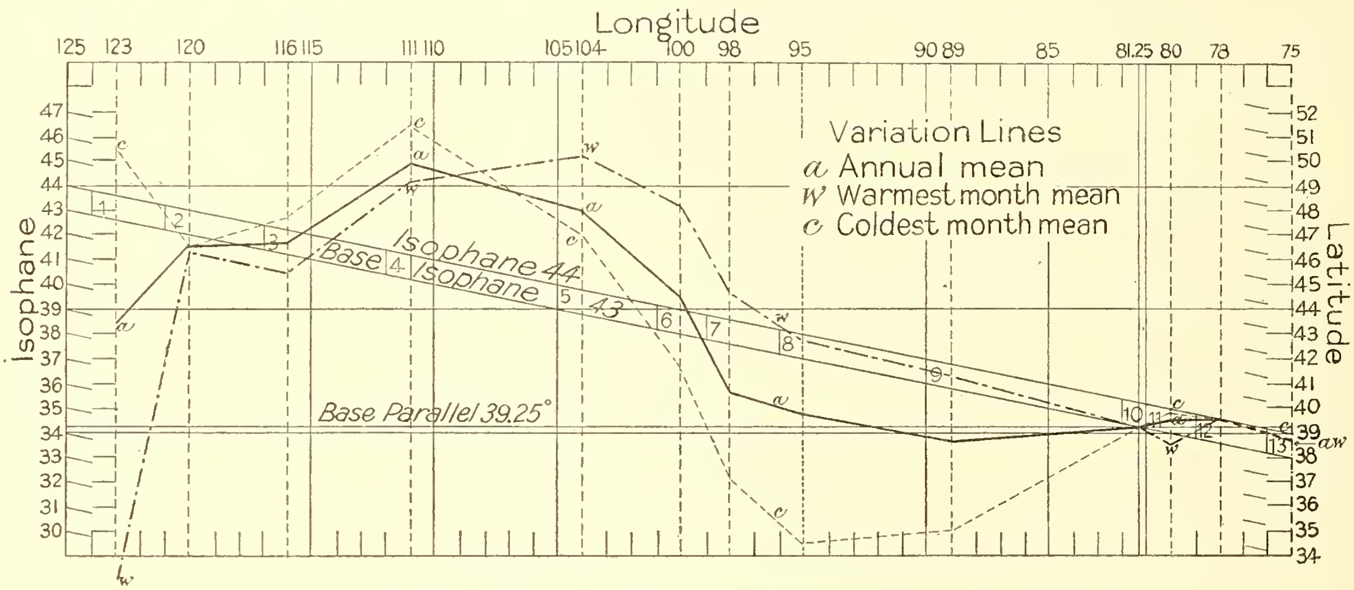

FIGURE 16.—Variations of the thermal means from isophane and latitude requirements.

TEST EXAMPLE BY THE ANNUAL, WARMEST, AND COLDEST MONTH THERMAL MEANS

In order to have a test example (no. 8) by thermal records to correspond with those of time records (examples 1 to 7), record cards were assembled from the card index file of record positions coming within a 1°×1° isophane-longitude quadrant approximately corresponding to the county quadrants and positions listed in examples 1, 5, and 6.

Since example cards A and C illustrate the method of finding the *lev*, zones, and zonal types represented by the subject records, *ri*, or *mri*, it is only necessary to give a list of the quadrants and average variations, zones, and zonal types for each, as taken directly from the computed averages of the variations on the record cards as in example 8 in which the plus and minus signs are not reversed from those on the record cards; hence minus in the example indicates lower isophane and warmer, and plus higher isophane and colder than the *ei*. Under *A. Precip.* is given the average annual precipitation in inches, with the *no.* number of record positions within the quadrant.

The principle of this chart is the same as that of figures 12, 14, and 15. The quadrants come between isophanes 43 and 44. Thus their positions correspond in general with those of the counties in example 1, and they are designated by the same numbers. The variations, as given in example 8 with plus and minus signs reversed in figure 16, show the relation of the *w* and *c* lines to the *a* line, which relation is an index to the *major types of climate*, as explained below. (Figs. 19 and 20).

The significant features of this chart, like those of the preceding, are in showing (1) that the general trend of the variation lines is with the isophane; (2) that the *a* variation line clearly represents the modifying influences of the major physiographic and climatic types across the continent during the year; and (3) that the *w* line represents the modifying influences during the warmest and summer months, while the *c* line represents the modifying influences during the coldest and winter months.

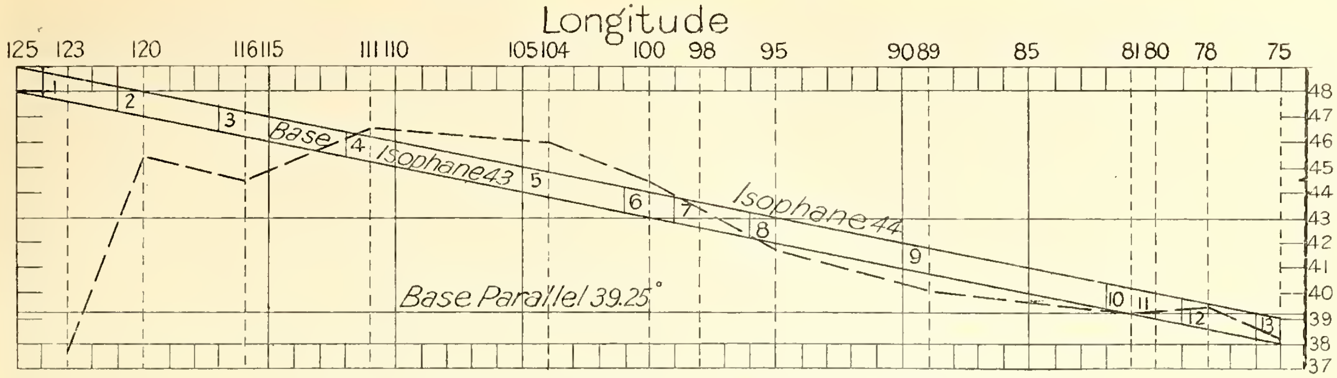

FIGURE 17.—Variations of the thermal effective sum from isophane and latitude requirements.

TEST EXAMPLE BY THE EFFECTIVE SUM OF THE MONTHLY MEAN TEMPERATURE

EXAMPLE 9.—*List of quadrants with average latitude equivalent variations and zonal types for the thermal effective sum*

Quad. no.	*ri*	*lev*	*zt*
1	53.75	+10.00	II .2
2	49.25	+1.50	.3
3	48.50	+1.75	−.3
4	53.25	−1.25	.2
5	52.50	−2.25	−.2
6	47.75	−1.50	+4
7	46.75	−.75	+.4
8	47.25	+.25	+4
9	45.50	+.50	.4
10	44.50	.00	.4
11	45.75	−.25	.4
12	44.75	−1.00	.4
13	43.25	−.25	−4
Average	48.00	+.51	---------

In example 9 the sum of the monthly means above 43° F. is taken as the subject, and the average sum is computed for the same quadrants from the records of the same set of stations as in example 8, with the record isophanes, variations, and zonal types determined from appendix table 5.[13]

This example gives the numbers of the quadrants, *ri* the record isophanes as found in appendix table 5 by the computed average sums, as determined from the record cards for the record positions within each quadrant; *lev*, the latitude equivalent variations (the plus and minus signs not reversed); and *zt*, the zonal types represented in table 5 by the record isophanes. The relations of the variations in this example to the isophane and parallel requirements are shown in figure 17, in which it is seen that the trend of the variations, except for position 1, is decidedly with the isophane requirements, and that the departures clearly represent the modifying influences of the major physiographic types as characterized by the western coast, western mountain, interior basin, eastern mountain, and eastern coast.

The variations in this chart are less marked than in figure 16, but are more accurate in representing the major physiographic and climatic types; they are especially significant in indicating the value of the thermal sum of the monthly means as an index to the interpretation of bioclimatic phenomena.

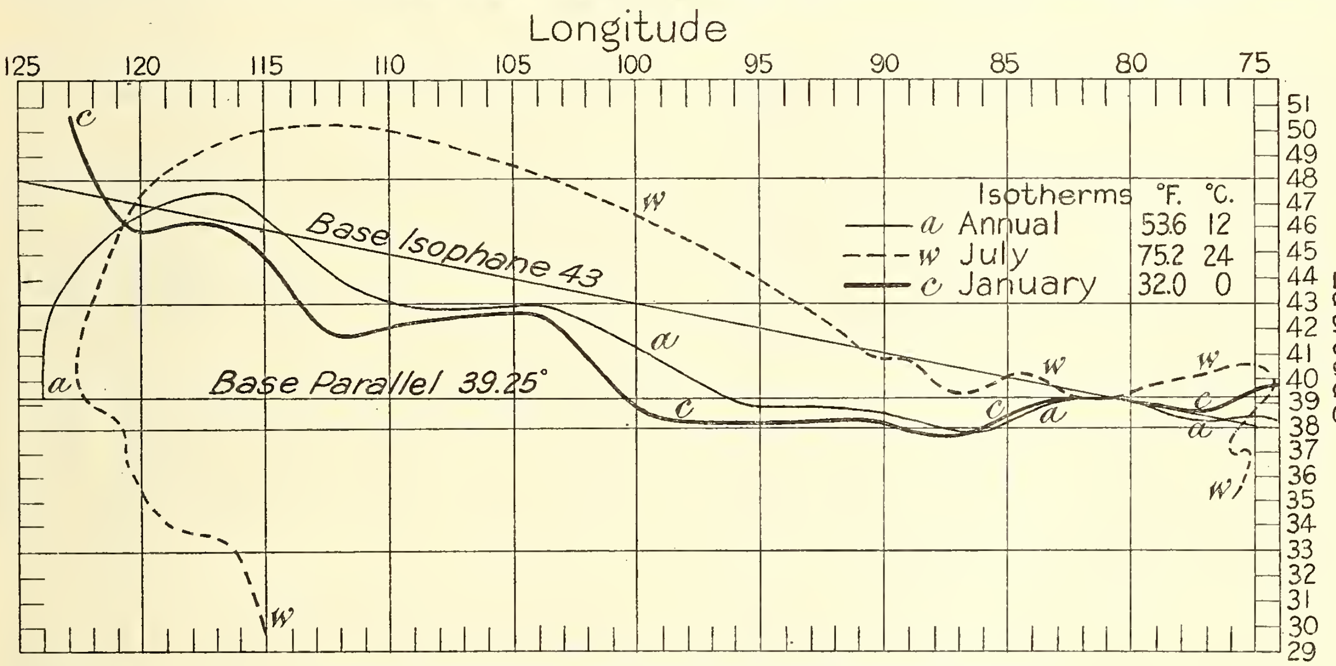

FIGURE 18.—Variations of the sea-level isotherms from isophane and latitude requirements.

TEST EXAMPLE BY THE ANNUAL, JULY, AND JANUARY ISOTHERMS

In figure 18 the annual, July and January isotherms, as given in Bartholomew's Physical Atlas, volume III, plate 7, are transferred to the isophane-latitude chart and adjusted by a slight change on the base meridian

[13] In this method the effective sum is not modified for positions above 2,000 feet further than the modifications of the constants in appendix table 5.

to represent their relations to the intercontinental base and to the base isophane and base parallel across the United States. By this method the isotherm lines are made available for direct comparison with the requirements of bioclimatic and astronomic laws and with the variation lines of the preceding charts.

In comparing here the isotherm variations from the isophane and latitude with the variation lines of the other charts, two very different principles are involved. The isotherm principle assumes a constant rate of lower temperature with higher altitude above the sea. While the rates adopted by different authors vary somewhat, the general average appears to be about 1° F. to 300 feet for both the annual and monthly means; so that the altitude in feet of a given record position, when divided by 300 (feet to 1°) is converted into equivalent temperature degrees, and when these (with certain modifications for barometric pressure and humidity) are added to the position temperature record, it is converted into its equivalent at sea level. Thus with the records of all stations across a continent converted in this manner to a common sea-level basis, they are assumed to be directly comparable, so that lines drawn on a map to represent positions or regions with equal sea-level temperatures serve to show the trend of the variation or departure from an assumed latitude requirement, normal, or average.

The marked differences in the two principles are in the rates and in the introduction of the requirement or base isophane and parallel to represent lines of equal phenomena. The principal agreement is in the bioclimatic variation lines and the meteorological isotherms, as they appear above and below the requirement parallel of latitude or isophane, and in the fact that they represent different interpretations of the effects of the same general physiographic causes as warmer departures above and colder departures below the latitude requirement constants as represented by parallels 39.25° and 43°, or any parallel between 38° and 48° relative to isophane 43 and its requirements.

Thus, while both the isotherm and isophane variation lines represent a measure of the variation in equivalent distance in degrees of latitude, there is a difference corresponding to the difference in the rate (or gradient) utilized and in the method of procedure, so that it is to be expected that there will be a considerable range of difference between the variation lines by the bioclimatic method and the isotherms by the meteorological method.

It is significant, however, that there is a broad general agreement between the trend of the *a*, *w*, and *c* variation lines in figure 16 and the corresponding annual, July, and January isotherms in figure 18 for the same meridians, and from the base isophane and parallel of latitude across North America. (See also figs. 6 and 23.)

There is one striking and significant difference in the relations of the isotherms of figure 18 to the variation lines of figure 16 relative to the major physiographic and climatic types across the continent, in that the bioclimatic variation lines represent the position altitude above sea level more nearly than do the isotherms, especially as related to the western mountain region in which the *c* line should occupy the higher position and the *w* line the lower relative to the *a* line, as in figures 16 and 19.

LIST OF POSITIONS AND THERMAL VARIATIONS ACROSS THE CONTINENTS

The object of this series of tests (figs. 19 to 22) is to show the results of a comprehensive study of the relations of the record *a*, *w*, and *c* temperature to representative isophanes and parallels across the continents of the Northern and Southern Hemispheres which involves the same principles and methods of procedure except that the *median* instead of the lower isophane of the quadrant is taken to represent its center and average altitude and temperature. Wherever, as across North America and Europe, sufficient records were available, averages for 1°×1° quadrants were utilized, but where sections of a continent, as through central Asia, are represented by only a few widely separated record positions, the records for quadrants of four or more 1° isophanes by 1° of longitude were utilized; and in a region like Tibet (fig. 19, Eurasia 6), where no records were available, the interpreted variation is represented by broken lines, as indicated by the trend of the isotherms. Another difference from the preceding isophane-latitude charts is that the base isophane and base parallel are designated as *requirement*, because they represent the requirements of bioclimatic and astronomic law as related to each position isophane and latitude.

The relative position of the given requirement parallel to the requirement isophane across the different continents was determined by the difference between the numerical designations of the intercontinental base isophane 43 and base latitude 39.25° across both hemispheres, which (to omit the fraction) is (43–39) 4°, so that for all isophanes except the equatorial (0) and any other isophane crossing the equator, the numerical designation of the requirement parallel is in each case 4° less than that of the given requirement isophane, or 4° more for the isophane than the numerical designation of the parallel of latitude, as shown in examples 10 and 11.

Example 10.—*List of test examples representing charted variations of the a, w, and c thermal means from representative requirement isophanes and parallels of latitude across the continents*

Continent	Ex. no.	Require. isophane		Re-quire. parallel	No. of stations	No. of quad.
Northern Hemisphere: [1]						
North America	1	47.00n	−4	43.00n	132	51
Do	2	43.00n	−4	39.00n	238	48
Do	3	33.00n	−4	29.00n	100	38
Eurasia	4	47.00n	−4	43.00n	69	39
Do	5	43.00n	−4	39.00n	95	50
Do	6	32.00n	−4	28.00n	123	60
Southern Hemisphere: [2]						
South America	7	.00	+4	4.00n	10	7
Do	8	10.00s	−4	6.00s	13	10
Do	9	32.00s	−4	28.00s	9	5
Do	10	47.00s	−4	43.00s	3	3
Africa	11	.00	−4	4.00s	9	9
Do	12	10.00s	−4	6.00s	10	9
Do	13	32.00s	−4	28.00s	11	9
Do	14	47.00s	−4	43.00s	14	9
Australia	15	10.00s	−4	6.00s	5	5
Do	16	26.00s	−4	22.00s	12	11

[1] As represented in fig. 19. [2] As represented in fig. 20.

The object of example 10 is to give a list of the number of test examples represented by the 16 continental charts for representative requirement isophanes and parallels in figures 19 and 20, with the corresponding requirement isophanes and parallels.

It is to be kept in mind that for the continents of the Western Hemisphere the requirement isophanes and parallels are relative to the base meridian of longitude 81 W., and for the continents of the Eastern Hemisphere they are relative to the equivalent base meridian 119 E.; therefore, the variation lines determined for the position and requirement isophane are also relative to the departure from the position and requirement parallel of both hemispheres.

POLEWARD AND EQUATORWARD VARIATIONS

It is important to keep in mind that for the continents of the Northern Hemisphere the poleward departures of the variation lines above the requirement isophane and parallel signify that the record temperature is warmer, and that the equatorward departures below the isophane or parallel signify colder than their requirement constants; while for the continents of the Southern Hemisphere the equatorward departures above signify colder, and the south-poleward departures below signify warmer than the isophane or parallel requirements.

TREND OF THE ISOPHANES THE SAME FOR THE NORTHERN AND SOUTHERN HEMISPHERES

It will be noted (figs. 19 and 20) that the northwest-southeast trend of the isophanes is the same across the continents of both the Northern and Southern Hemispheres. While they represent the same requirements of the bioclimatic law as lines of equal phenomena, the requirement for warmer temperature westward and cooler eastward from any given meridian of theNorthern is the reverse of that from any given meridian of the Southern Hemisphere, in that for the latter the requirement is for cooler westward and warmer eastward.

Example 11.—*Requirement parallels corresponding to north and south parallels of the same numerical designation*

Northern Hemisphere				Southern Hemisphere			
North		South polew.	Requir. parall.	South		North polew.	Requir. parall.
Isop.	Lat.			Isop.	Lat.		
4.00n	4.00n	−4.00	0.00	0.00	0.00	−4.00	4.00n
3.00n	3..00n	−4.00	1.00s	1.00s	1.00s	−4.00	3.00n
2.00n	2.00n	−4.00	2.00s	2.00s	2.00s	−4.00	2.00n
1.00n	1.00n	−4.00	3.00s	3.00s	3.00s	−4.00	1.00n
.00	.00	−4.00	4.00s	4.00s	4.00s	−4.00	.00

These reversed relations correspond with the fact that for the northern continents the westward trend of the isophanes is north-poleward and the eastern trend equatorward, while for the southern continents the eastward trend is south-poleward and westward trend is equatorward.

In any comprehensive comparative study of the charted variations it is therefore quite important to have a clear understanding of the principle of reversal in relatively warmer or cooler temperatures toward the western and eastern coasts of the northern and southern continents, and also of the reversal of plus warmer variations coming north-poleward above the requirement isophane or parallel for the northern and south-poleward below for the southern continents with a like reversal for the minus variations except in figure 22.

VARIATIONS RELATIVE TO THE EQUATOR AND THE 1° TO 4° ISOPHANES NORTH AND SOUTH OF IT

As shown in example 11, when a given requirement isophane (e. g., isophane 0) crosses the Equator on the one hundredth meridian of the Western or Eastern Hemisphere, the corresponding requirement parallel relative to the continental areas north of the Equator is (latitude 0°−4°) 4° south, and for areas south of the Equator it is (latitude 0°+4°) 4° north. In a like manner the corresponding requirement parallel for isophanes 1 to 4 north and for isophanes 1 to 4 south are as given in example 11, which illustrates the principle that, because the base latitude with its numerical designation 39 is 4° less than the base isophane 43, a requirement parallel corresponding to any given isophane in a table of constants must be 4° less than the isophane for both the Northern and Southern Hemispheres; and, since equatorward is south-poleward for the continental areas of the Northern Hemisphere, and north-poleward for those of the Southern Hemisphere, the isophanes and parallels of the same numerical designation 1° to 4° north of the Equator on the one hundredth meridian will be represented by a difference of 4° on the Equator south for the Northern, and 4° north for the Southern Hemisphere. In this example, *Isop.* and *Lat.* give the isophanes and parallels of the same number, which *south-poleward* for the Northern Hemisphere minus 4° give the number of the requirement parallel south (s) for the Northern and north (n) for the Southern Hemisphere. This principle also applies to requirement isophanes and parallels in the charts for South America 7 and Africa 11 in figure 20.

Figures 19 and 20 give the results of additional tests of the variation of the *a*, *w*, and *c* thermal mean records from their respective requirement isophanes and parallels across the continental areas of the Northern and Southern Hemispheres. The minor charts 1 to 16 show the results of test examples for positions on or near representative isophanes. The intervals for the parallels and meridians are 10°; the parallels are numbered at the right and left and the meridians below each minor chart; and the names of the countries or political divisions through which the isophane passes are given, with the approximate longitude of the borders between them marked by short vertical lines. The principle of the variation lines relative to the requirement isophanes and parallels is the same as that of the preceding isophane-latitude charts (figs. 12 to 18).

RANGE OF ERROR AND PURPOSE SERVED

While in figures 19 and 20 there is necessarily a considerable range of error in the given relations of the variation lines to their isophane and latitude requirements, especially through regions for which there are but few or no available records of temperature, it is evident that the errors are no greater than those in published isotherms across maps of the same region.

Regardless of unavoidable error in representing actual variations for specific political divisions and local regions, it will be realized that the purpose is served in showing (1) the results of test examples for representative isophanes and parallels of latitude across the continents; (2) the trend of the variation lines from the requirement isophanes and corresponding requirement parallels; and (3) the influence of the major physiographic features on the major climatic types, as characterized by the relation of the *w* and *c* lines to the *a* line, in which for the Northern Hemisphere *w* above and *c* below *a* expressed as *wac* signifies interior, basin, or continental influences, while the reverse relation expressed as *caw* signifies coastal or mountain influences. Where one of these lines crosses the requirement isophane its normal isophane requirement is met because the record average for the quadrant agrees with its constant. In a like manner, where an *a*, *w*, or *c* variation line crosses the requirement parallel its normal latitude requirement is met. When the trend of the variation lines across a continent is plainly with that of the isophane it is in support of the requirements of bioclimatic law, and when the trend is more distinctly with the parallel it is apparently in support of astronomic law.[14]

[14] It is not necessary in support of this law because across regions with large bodies of inland waters like the Mediterranean Sea there is a profound modification of the requirements of the bioclimatic law.

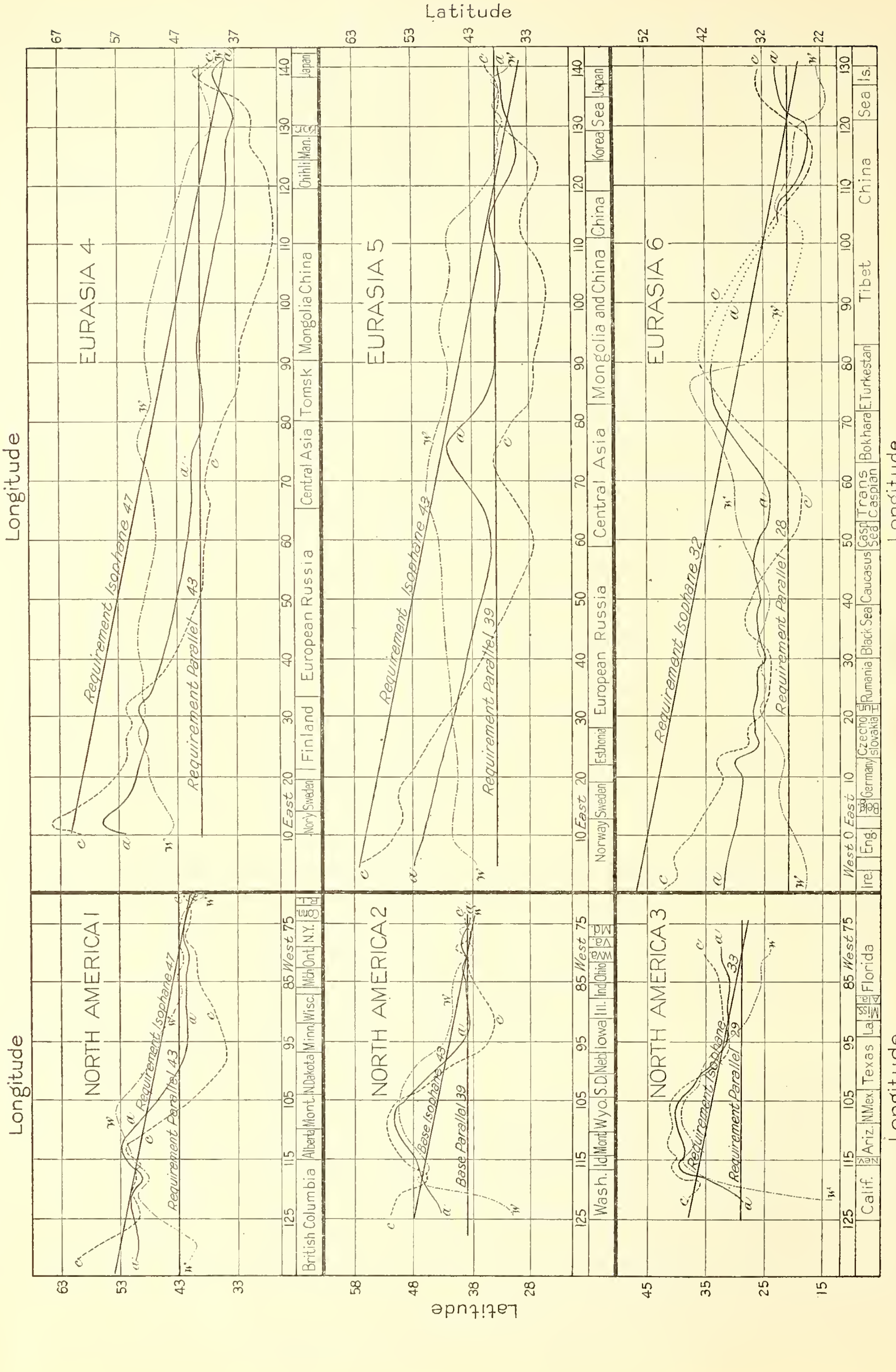

Figure 19.—Comparison of thermal mean variation lines from representative requirement isophanes and parallels across the northern continental areas.

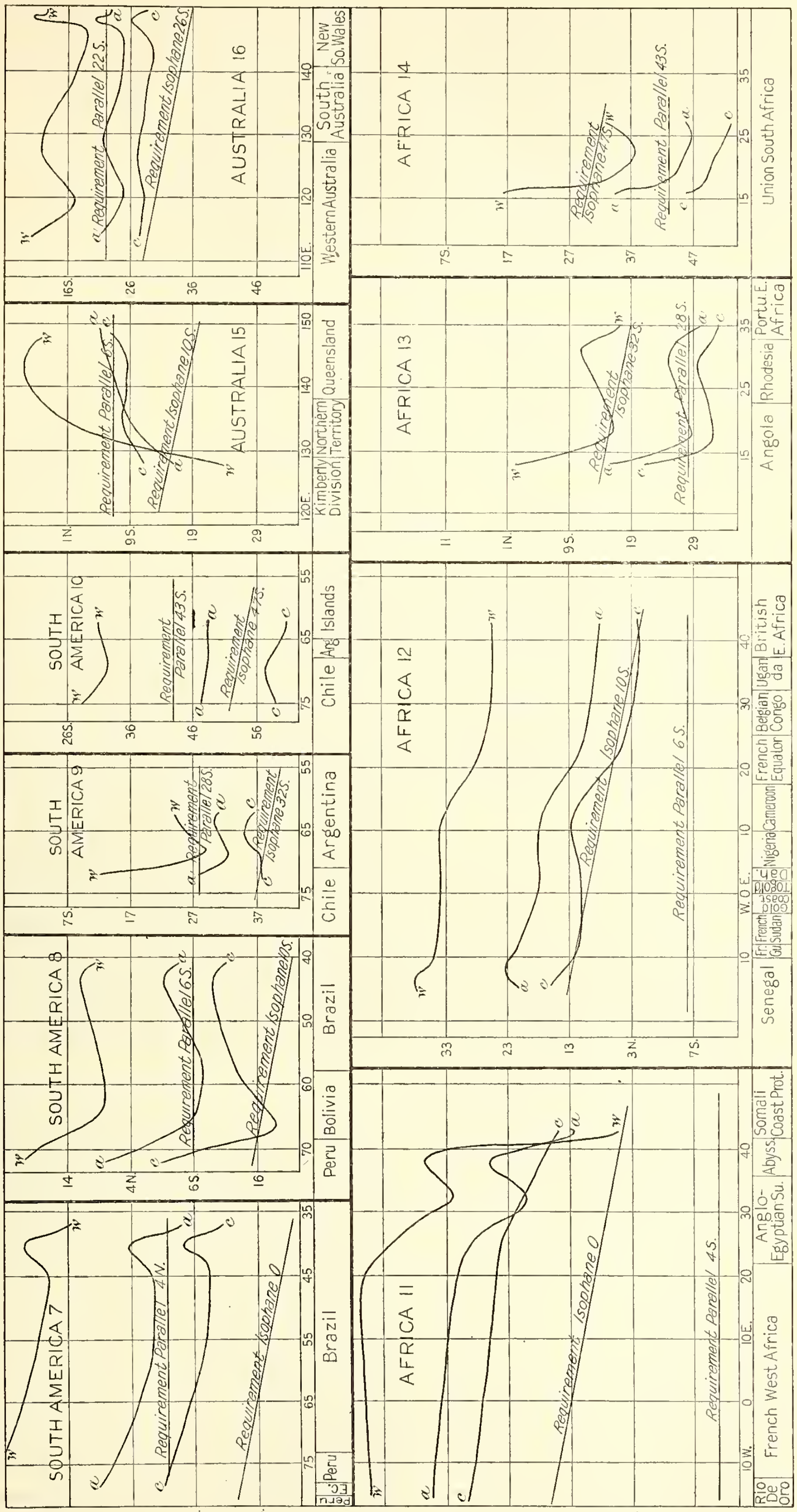

FIGURE 20.—Comparison of thermal mean variation lines from representative requirement isophanes and parallels across the southern continental areas.

The distance of the average *a*, *w*, or *c* variation line above the isophane across a northern continent or region indicates the relative intensity of the influences which cause a warmer departure than the requirement constant for the given region. Conversely, the lines below the isophanes for a northern continent indicate lower temperatures than the requirement constants; while for a southern continent the position of the variation lines equatorward above the isophane or latitude signifies colder (and when below, warmer) than the requirement. So in each of the 16 continental charts the distance of the *a*, *w*, and *c* variation lines from the requirement isophane, or parallel, on any given meridian indicates the relative intensity of the prevailing influences which cause the warmer or colder departures from the requirement constants.

Thus the variation lines serve their purpose much better than the sea-level isotherms, because the variation lines are more specific as related to geographic positions and quadrants *at the specific or average altitude* of the positions in the regions represented by the given isophane.

COMPARISON OF ANNUAL MEAN VARIATIONS FOR THE WEST AND EAST COASTS OF THE CONTINENTS

Example 12 gives the determined variations of the *a* average from the requirement *latitude* constants for the western (*WC*) and eastern (*EC*) coasts, as represented in the 16 example charts of figures 19 and 20; with averages for the 6 examples of the Northern Hemisphere and the 10 examples of the Southern, and finally a grand average of the 16 examples of both hemispheres.

In finding the average variations for each hemisphere the sum of the differences between the plus and minus variations is divided by the number of examples, but for the grand average for both hemispheres the sum of the average variations for each coast is divided by 2, regardless of the sign, because the minus variations for the Southern, and the plus variations for the Northern Hemisphere are both north-poleward, as charted, so that as related to the Northern Hemisphere both *WC* and *EC* would be plus, and to the Southern they would be minus; thus the grand average is designated as plus or minus.

The relations of these average variations for the west and east coasts, and especially the trend of the *a* variations from the latitude requirement represented by connecting lines between the west and east positions, is shown much better by the chart than by the tabular method, as in figure 21.

In figure 21 the 16 charts of figures 19 and 20 were reduced to an equal width on cross-section paper, but with the latitude at the same scale of 10° to the inch, and with each requirement parallel drawn in its proper position relative to the requirement isophane. While this gives a greater angle of trend to the isophane and variation lines for the wide continental areas, they are in each chart relative to the parallel and to the coast-to-coast trend of the variation line.

It will be noted that there are only two (North America 3 of the Northern and Australia 15 of the Southern Hemisphere) in which the trend of the *a* variation line is the reverse of that of the isophane requirement, and only one (Australia 16) in which the trend is more nearly with the latitude than with the isophane requirement; so that, in general, in both hemispheres the trend of the variation lines is far more nearly in accordance with the requirement of bioclimatic law than with that of astronomic law.

In figure 22, which is based on the Northern Hemisphere and Southern Hemisphere averages and the grand average variations of example 12 and figure 21, the parallels within the range of the trend lines are represented at intervals of 1° and are numbered from 38 to 50, base parallel 39, thus serving as a scale for the measurement of the variations from the latitude requirements. Thus for the west coasts of the Northern Hemisphere the average variation from the requirement is +8.12° warmer north-poleward and for the Southern Hemisphere −10.57° colder north-poleward, while for the east coast it is −0.50° colder south-poleward for the Northern Hemisphere and −2.42° warmer north-poleward for the Southern; and for the average for the Northern and Southern Hemispheres it is ±9.34° for the west, and ±0.96° for the east coast.

Example 12.—*Comparison of the annual mean variations from the requirement latitude constants on the west and east coasts of the continents*

North America			Eurasia			South America			Africa			Australia		
No.	*WC*	*EC*	No.	*WC*	*EC*	No.	*WC*	*EC*	No.	*WC*	*EC*	No.	*WC*	*EC*
1	+7.00	−2.75	4	+12.75	−3.75	7	−11.25	+2.00	11	−46.00	−23.50	15	+10.25	−1.50
2	+4.25	−.50	5	+13.75	−1.00	8	−13.50	−2.00	12	−26.75	−14.00	16	−.75	+.75
3	−.25	+3.25	6	+11.25	+1.75	9	−.75	+3.25	13	−12.75	+2.00			
						10	+4.50	+5.75	14	−8.75	+3.00			
Average Northern Hemisphere				+8.12	−.50	Average Southern Hemisphere							−10.57	−2.42
						Grand world average							±9.34	±.96

OUTSTANDING FEATURES OF THE CHARTED VARIATIONS

In a comprehensive study of these 16 charted examples, the outstanding features are (1) that the *general average trend* of the *a* variation lines *is with that of the isophanes* across all continents of the Northern and Southern Hemispheres, except North America 3 and Australia 15 and 16; (2) that the widest departure of the *a* variation line from the isophane and latitude requirements is across coastal, mountain, and interior regions of marked physiographic influences; (3) that for the coastal and mountain regions the influences cause a higher or poleward (warmer) trend of the *a* variation line, and that for the interior plains and basin regions the influences cause a lower equatorward (colder) trend; and (4) that the influences of the distinctive coastal, mountain, and interior regions on the warmer or colder trend of the *w* and *c* variation lines relative to the *a* line in each example serve to characterize the type of major influences across the distinctive regions of the continents and thus to indicate their major climatic types.

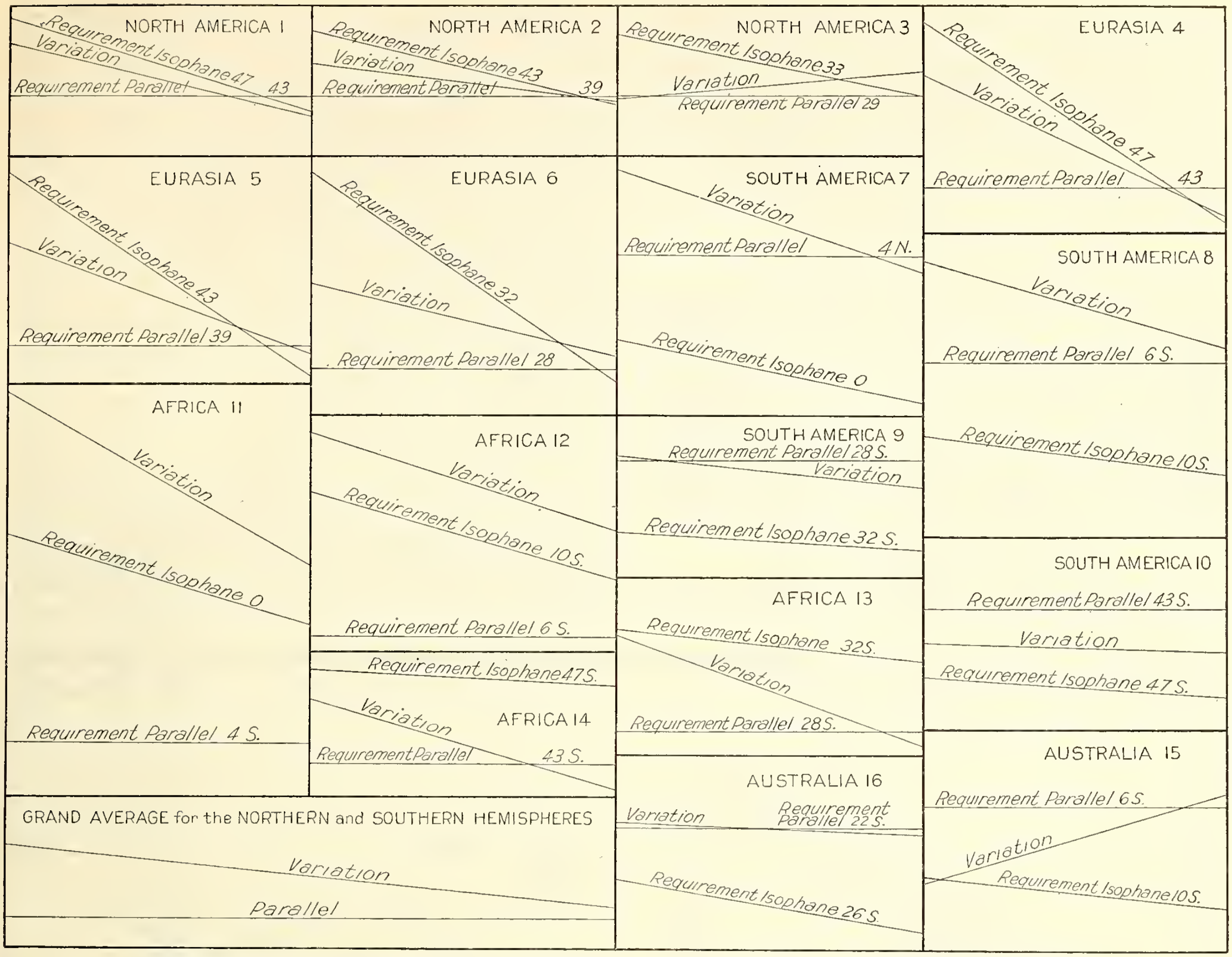

FIGURE 21.—Comparison of the average trend of the annual mean variation between the eastern and western coasts of the continents.

The most outstanding and significant feature, however, of this set of comprehensive tests, is the fact that in general the trend of the variation lines much more nearly meets the requirements of the bioclimatic law and isophane than those of the astronomic law and parallel of latitude.

Another significant feature is the fact that for the Northern Hemisphere the trend from the requirements of astronomic law is plainly indicative of warmer temperatures north-poleward toward the west coast and colder equatorward or south-poleward toward the east coast; and that for the continental areas of the Southern Hemisphere the trend of the departures from the requirement is the reverse of that for the northern continents. The two notable exceptions are in figure 21 (North America 3 and Australia 15), which are plainly due to peculiar gulf or ocean influences.

An additional feature in figures 19 and 20 is the plain indication that, relative to the isophane requirements, the *a*, *w*, and *c* mean temperatures are very much colder across the continental areas of the Southern Hemisphere than across the corresponding areas of the Northern Hemisphere. This conforms to the well-known fact relative to the parallels of latitude of the same numerical designation, but the variations from the requirement isophane bring out this fact far more convincingly than do the variations of the isotherms from the requirement parallels, and thus again point to the isophane as the most reliable basis of reference for the interpretation of thermal and bioclimatic phenomena across the continents.

Further striking evidence in support of the isophane principle and method is found in the *a*, *w*, and *c* variation indices to the major types of climate of the Northern as compared with those of the Southern Hemisphere. For the continents of the Northern Hemisphere there are two distinctive major types: (1) The *caw* major type of the coastal and mountain regions with rela-

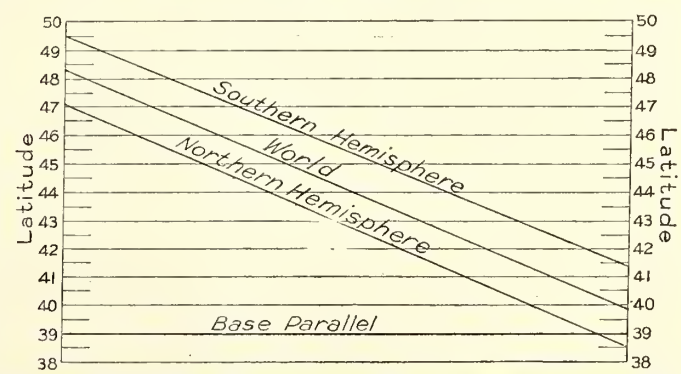

FIGURE 22.—Average trend of the annual mean variation lines for the Northern and Southern Hemispheres and for the world.

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tively cool *w* means and seasons and relatively warm *c* means and seasons; and (2) the *wac* major type of the interior continental regions and basin with relatively hot *w* means and relatively cold *c* means and corresponding seasons. While for the continental areas of the Southern Hemisphere there is in general but one (*caw*) major type even across the interior and basin regions; there are, however, some local exceptions, of which Australia 15 is a most remarkable one in that the *wac* type occupies the western coast.

THERMAL VARIATIONS AND AGRICULTURE

In a study of the preceding examples of variations of the thermal means from the isophane and latitude requirement constants, it will be realized that they have a direct bearing on local, regional, and world agriculture. Many new lines of research and application are suggested in which the variations from the isophane relative to the thermal types of climate, thermal zone, and zonal types, may serve as guides to the solving of many world-wide problems of great importance in the complicated economics of production.

TEST EXAMPLES BY THE ISOTHERMS

By comparing *isotherm* maps with *isophane* maps of the same continents and countries it will be seen that across all continental areas of the Northern and Southern Hemispheres the general trend of the sea-level isotherms for the average temperature is more nearly in accordance with bioclimatic than with astronomic law. Thus in the isotherms of the world (Bartholomew's Physical Atlas, v. 3, pl. 1, 1899) we find a basis for test examples by representative isotherms 30° and 70° F. north and south, the heat equator, and in the other annual and monthly isotherms (fig. 23).

Taking the higher limits of the isotherms across Eurasia and northern Africa, and across North America, the general average trend is about as near to the isophane requirements of bioclimatic law as the trend of the lower limits is to those of the astronomic law. Also, the general trend of the heat equator across the continents is in agreement with the bioclimatic law. Across the Southern Hemisphere isotherm 70° is in accordance with bioclimatic law, but less so across Australia, and greatly in excess of the requirements across Africa and South America. Isotherm 30° F. south is over the oceans throughout and in accordance with astronomic law, in striking contrast to the trend of the same isotherm across the Northern Hemisphere where land prevails. The general average trend of this isotherm across both the Northern and Southern Hemispheres is relative to parallel 60° north and south.

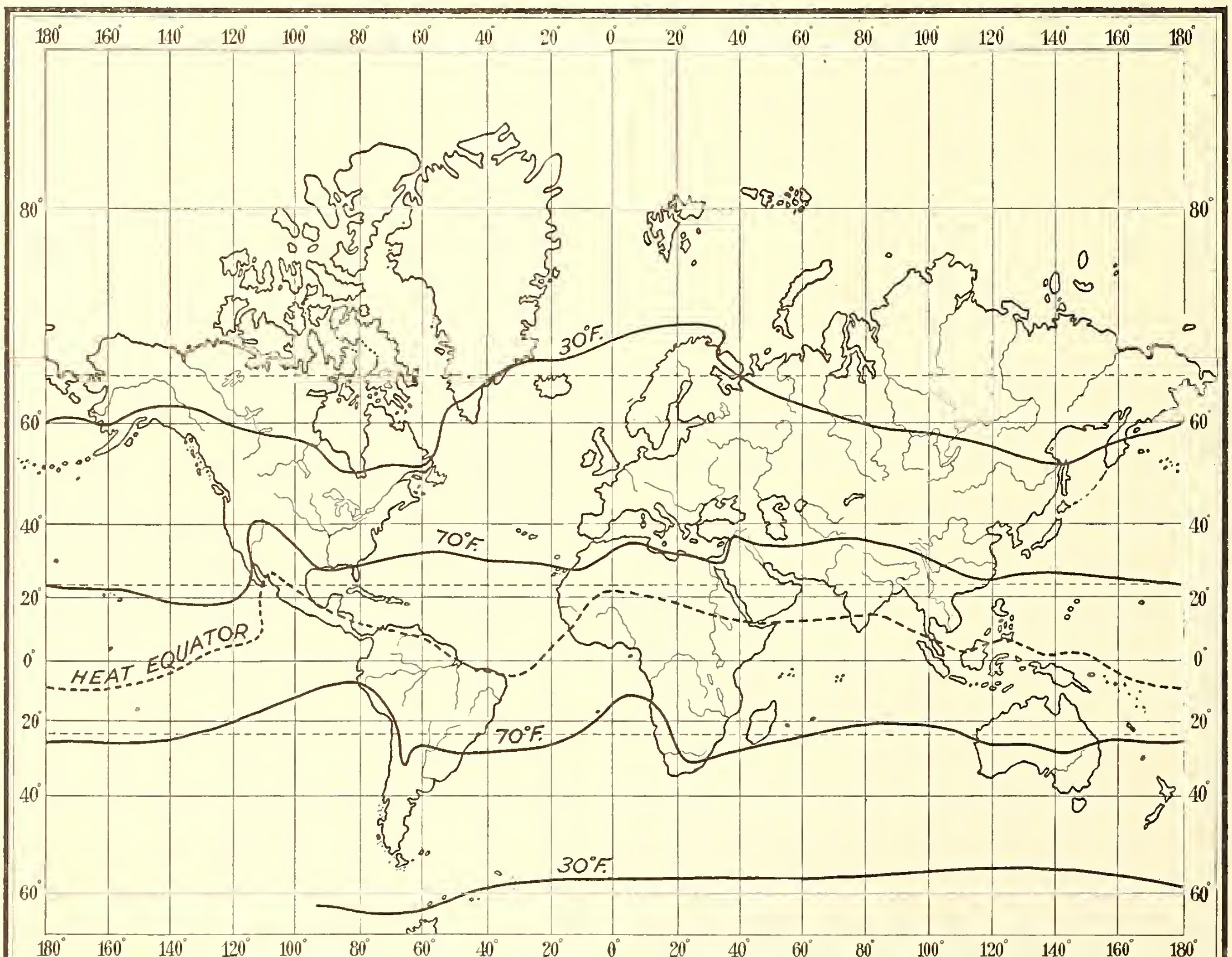

FIGURE 23.—Mean annual isotherms for 70° and 30° F., north and south, and the heat equator for the world.

Isotherm 60° F. south (Bartholomew's Atlas) is nearest the southern coast of Australia and in close agreement with the course of the isophanes. Isotherm 65° south comes close to the southern coast of Africa, while isotherm 35° comes close to the southern coast of South America. The striking and outstanding feature of all of the southern isotherms is in the extreme northwestward trend along the west coasts of Africa and South America in which they very greatly exceed the northwestward trend of the isophanes. Thus across the continental areas the general or average trends are more nearly in accordance with the requirements of bioclimatic than that of astronomic law. Wherever there is less evidence in support of this law, or the exceptions are more striking, it may be assumed that it is due to the local or region physiographic factors of land and water, or both.

MEAN MONTHLY ISOTHERMS

The general northwestward trend of the isotherms for all months is plainly evident across the continental areas of the Western Hemisphere, but much less evident across the southern section of the Eastern Hemisphere in Eurasia and Africa for the warmer months. It is a curious and interesting fact that, while the greatest variation from latitude is shown for these months across North America, except the marked reverse on the western coast, a less and even reverse (southwest) variation is evident across Eurasia in June and July for some of the isotherms. This is plainly due to the same general causes that affect the western coast of North America, with its mountain ranges near the coast; while the absence of high north-to-south mountain ranges in Europe and the presence of great inland seas serve to extend the western coast influence and climatic type eastward over a vast area.

TEST EXAMPLES BY DISTANCE RECORDS

Distance in bioclimatics is represented by degrees of isophane or latitude poleward and equatorward, degrees of longitude east and west from a given geographic position, and by feet or meters of altitude of a position above the level of the sea, or its *equivalent isophane* or *latitude* in degrees of latitude. The requirement constants of the bioclimatic law in units of time and temperature are coordinates with distance in degrees of latitude or isophane, and in feet above sea level, because the units of time and temperature may be expressed in equivalent units of distance and, vice versa, units of distance may be expressed in equivalent units of time or temperature.

SUBJECTS

In addition to isophane, latitude, and altitude distances in tables of constants, and in equivalent variations for time and thermal subjects, the principal subjects of distance as applied in bioclimatics are: (1) The geographic range and limits by isophanes at and by altitudes above sea level of (*a*) plants and animals, (*b*) climates, (*c*) seasons, (*d*) bioclimatic zones and zonal types, and (*e*) agricultural products; and (2) climatic timber line and snow line.

SYSTEMS

Systems relative to distance subjects are represented in (*a*) tables of isophane and altitude constants; (*b*) isophane and altitude index cards, or cards of record positions as entered in lists of position records; and (*c*) lists of determined variations in equivalent degrees of latitude or feet of altitude.

The principle and methods of dealing with distance subjects are the same as with time and temperature, in that the table of isophane and altitude distance constants serves as the fundamental basis of reference to determine the latitude or altitude variation of the record for a given position from the requirement constants of bioclimatic law; this variation for a given position, or list of positions, then serves as the *latitude variation index* or *altitude variation index* to the isophane equivalent index, which referred to the table of constants gives the desired interpretation of the limit isophane or altitude. Thus the essential elements of the principle and method of interpretation are (1) the *lvx* latitude variation index, (2) the *avx* altitude variation index, and (3) the *iex* isophane equivalent index, as shown in example 13.

Example 13.—*Interpreted altitude limits for winter wheat culture based on the period variations of example 3 and appendix table 11*

SECTION A

pno	*pi*	Altitude limit constants					Indices		
		ll	*lol*	*mo*	*hol*	*hl*	*lvx*	*iex*	*avx*
1	43.25	−2,900	−1,300	−100	+1,100	+2,700	+7.25	50.50	−2,900
2	43.00	−2,800	−1,200	0	+1,200	+2,800	+1.25	44.25	−500
3	43.00	−2,800	−1,200	0	+1,200	+2,800	.00	43.00	0
4	43.25	−2,900	−1,300	−100	+1,100	+2,700	−4.50	38.75	+1,800
5	43.50	−3,000	−1,400	−200	+1,000	+2,600	−7.50	36.00	+3,000
6	43.25	−2,900	−1,300	−100	+1,100	+2,700	−.25	43.00	+100
7	43.00	−2,800	−1,200	0	+1,200	+2,800	+.50	43.50	−200
8	43.00	−2,800	−1,200	0	+1,200	+2,800	+2.50	45.50	−1,000
9	43.25	−2,900	−1,300	−100	+1,100	+2,700	+2.25	45.50	−900
10	43.00	−2,800	−1,200	0	+1,200	+2,800	.00	43.00	0
11	43.00	−2,800	−1,200	0	+1,200	+2,800	−3.25	39.75	+1,300
12	43.00	−2,800	−1,200	0	+1,200	+2,800	−1.50	41.50	+600
13	43.00	−2,800	−1,200	0	+1,200	+2,800	−2.75	40.25	+1,100

SECTION B

pno	Indices		Interpreted altitude limits					*pa*	*abl*
	iex	*avx*	*ll*	*lol*	*mo*	*hol*	*hl*		
1	50.50	−2,900	------	------	------	------	−200	100	+300
2	44.25	−500	------	------	------	+700	+2,300	1,800	−500
3	43.00	0	------	------	0	+1,200	+2,800	2,400	−400
4	38.75	+1,800	------	+500	+1,700	+2,900	+4,500	3,900	−600
5	36.00	+3,000	0	+1,600	+2,800	+4,000	+5,600	4,600	−1,000
6	43.00	+100	------	------	0	+1,200	+2,800	1,800	−1,000
7	43.50	−200	------	------	------	+1,000	+2,600	1,400	−1,200
8	45.50	−1,000	------	------	------	+200	+1,800	1,000	−800
9	45.50	−900	------	------	------	+200	+1,800	700	−1,100
10	43.00	0	------	------	0	+1,200	+2,800	600	−2,200
11	39.75	+1,300	------	+100	+1,300	+2,500	+4,100	2,000	−2,100
12	41.50	+600	------	------	+600	+1,800	+3,400	400	−3,000
13	40.25	+1,100	------	−100	+1,100	+2,300	+3,900	100	−3,800
Zonal types	------	------	11 .6	−5	−4	.4	+.3	------	------

TEST EXAMPLES BY ALTITUDE LIMITS OF WHEAT CULTURE

The altitude limits of wheat culture will serve as a representative test example of the geographic range and limits by altitudes above sea level of plants and animals in general.

Example 13 shows how the altitude range and limits of commercial wheat culture are interpreted and the variation from the requirements of bioclimatic law are determined. Here *pno* gives the position numbers, and *pi* the position isophanes of example 1, with *ll* the low, *lol* low optimum, *mo* midoptimum, *hol* high optimum, and *hl* high limit altitude constants of *pi* in appendix table 11; *lvx* gives the latitude variation index (same as *P lev* of example 3), as determined from the period record in example 1, which plus or minus *pi*

gives the *iex* isophane equivalent index; e.g., for position 1 in this example, *pi* 43.25 + *lvx* 7.25 equals *iex* 50.50, which referred to table 11 gives the interpreted *hl* high limit at −200 feet below sea level, as in section B; or, for position 5, *pi* 43.50 − *lvx* 7.50 equals *iex* 36.00, which referred to table 11 gives the interpreted *hl* high limit at 5,600 feet above sea level, as in section B.

The same results are attained by multiplying the *lvx* by 400 (feet to 1°) to find the *avx*, which plus or minus the *pi* altitude constants for *hl* in table 11 gives the interpreted limits; e.g., for position 1, *lvx* +7.25 × 400 equals *avx* −2,900, and this minus *hl* constant +2,700 equals the interpreted *hl* limit −200 feet; or for position 5, *lvx* −7.50 × 400 equals +3,000, which plus *hl* constant +2,600 equals interpreted *hl* limit +5,600 feet. Another method is to find the difference between the *avx* and the *hl* constants; e.g., for position 1, *hl* +2,700 minus *avx* −2,900 equals interpreted *hl* −200 feet; or for position 5, *hl* constant +2,600 plus *avx* +3,000 equals interpreted *hl* +5,600 feet.

Section B gives the same position numbers with the *iex* and *avx* for *pi* in section A, in which *iex* referred to table 11 gives its *ll*, *lol*, *mo*, *hol*, and *hl* altitude constants and the interpreted limits for *pi;* or *avx* plus or minus the altitude *ll* to *hl* constants for *pi* in section A gives the same results. Then *pa* plus or minus the interpreted *hl* limit gives the *abl* altitude of the position above or below the interpreted *hl.*

Interpretations for Nonrecord Positions

With the period *lev*, as in example 3, or *lvx*, as in example 13, determined for a given position, or for the average of a number of positions within a local region, it is utilized to correct the *pi* of any other position within the local area or region, and to find its *iex*, which referred to table 11 gives at once the interpreted limits above its position altitude; or with the period *avx* determined, the high altitude limit of any position within the county or quadrant will be the *hl* constant for its position isophane plus or minus its *avx;* e.g., for position 5 the altitude variation index is (*lvx* −7.50 × 400) +3,000 feet, which plus the *hl* constant for any isophane position within the county or quadrant gives approximately the interpreted high limit above or below its altitude.

Interpretations by Record Limits

If the high altitude limit of winter wheat culture is known from records at a given position, the high limit and corresponding lower limits can be interpreted for other positions within the same local area or region by simply referring the record altitude limit to the corresponding high-limit constant in table 11, which gives the *iex* and corresponding lower limits relative to the *pi.*

Example 14.—*Interpreted high and low altitude limits and optimum altitudes for winter wheat culture*

SECTION A. HIGH LIMITS

	pi	*plo*	*rhl*	*hlc*	*avx*
Northern Hemisphere:					
North America:					
2. Washington	43.00N	117W	2,300	2,800	−500
4. North Dakota	48.00	97	900	800	+100
Eurasia:					
Ex. 21 Swiss Alps	29.50	--------	5,500	8,200	−2,700
7. Sweden	43.00	18E	100	2,800	−2,700
8. Union of Soviet Socialist Republics	43.00	50	200	2,800	−2,600
12. Japan	48.00	140	0	800	−800
Southern Hemisphere:					
2. South America	36.00S	72W	0	5,600	−5,600
2. Africa	48.00	20E	4,800	800	+4,000

Example 14.—*Interpreted high and low altitude limits and optimum altitudes for winter wheat culture*—Continued

SECTION B. LOW LIMITS

			rll	*llc*	
Northern Hemisphere:					
15. Texas	33.00N	96W	500	1,200	−700
18. Greece	21.00	22E	600	6,000	−5,400
Southern Hemisphere:					
1. South America	17.00S	66W	3,000	7,600	−4,600
1. Australia	24.00	137E	0	4,800	−4,800

SECTION C. OPTIMUM CENTERS

			rmo	*moc*	
Northern Hemisphere:					
1. Kansas	38.00N	98W	1,900	2,000	−100
3. Illinois	40.00	89	500	1,200	−700
7. Hungary	30.00	20E	300	5,200	−4,900
13. England	32.00	0	200	4,400	−4,200
Southern Hemisphere:					
1. South America	23.00S	60W	100	8,000	−7,900
3. Australia	27.00	144E	800	6,400	−5,600
1. Australia	24.00	137	0	7,600	−7,600

INTERPRETATION OF THE ALTITUDE VARIATION INDEX BY RECORD LIMITS

If the record low, midoptimum, or high altitude limit is known for a given position the *avx* is simply the difference between the record altitude and the position constant for the position isophane in table 11, and this index is applied to find the corresponding limits within the area or region represented by the record, as in example 14, which gives (sec. A) representative *rhl* record high altitude limit positions for winter wheat culture, as interpreted from the average altitude of the highest north and south poleward 1° quadrants on maps showing the geographic distribution of winter wheat culture,[15] and its *pi*, *plo*, and average *pa* (which in this example equals *rhl* the record high limit in section A), *rll* record low limits (sec. B) and *rmo* record midoptimum (sec. C); *hlc* in section A gives in appendix table 11 the high limit constant for *pi*, *llc* in section B the low limit constant; and *moc* in section C the midoptimum constant for *pi;* while *avx* gives the altitude variation index of the record altitude from the altitude constant in all three sections.

Thus with the high altitude limit known for an average position in a given 1° quadrant, as in North America, position 2, *pi* 43, *rhl* as 2,300 feet, and the constant for *pi* in table 11 as 2,800 feet, the *avx* or *rhl* is (*hlc* 2,800 minus *rhl* 2,300) 500 feet below the constant; or for North America, position 4, the *rhl* is (*rhl* 900 minus *hlc* 800) 100 feet above the constant.

To get the same results by the latitude equivalent method the *rhl*, *hlc*, and *avx* altitude are reduced to latitude equivalents by dividing them by 400 (feet to 1°). This gives for North America, position 2 (*rhl*) *le* +5.75; (*hlc*) *le* +7.00; and (*avx*) *le* −1.25. As applied to this position, *pi* 43.00 plus (*rhl*) *le* 5.75 equals *ri* 48.75, and *pi* 43.00 plus (*hlc*) *le* 7.00 equals *ei* 50.00, and *ei* 50.00 minus *ri* 48.75 equals *lvx* +1.25, which × 400 equals *avx* −500; while for North America, position 4, *pi* 48.00 plus (*rhl*) *le* 2.25 equals *ri* 50.25, and *pi* 48.00 plus (*hlc*) *le* 2.00 equals *ei* 50.00, and *ei* 50.00 minus *ri* 50.25 equals *lvx* −0.25, which × 400 gives *avx* +100 as in example 14. For nonrecord positions the *avx* is utilized to correct the position altitudes.

In these, as in all other positions of this example, *ri* in the isophane column of table 11 gives zone +.3 for

[15] Finch, V. C., and Baker, O. E. GEOGRAPHY OF THE WORLD'S AGRICULTURE. U. S. Dept. Agr., Off. Sec. 149 pp., illus. 1917.

the high limit, and the position altitude record in the *hl* column gives the same zone.

It is to be kept in mind that the record or interpreted altitude of any one of the *ll* to *hl* limits above or below a given position when referred to table 11 gives the altitude relations of all the limits to the given position; thus with the record or interpreted *mo* at sea level, the *hol* is at 1,200 and the *hl* is at 2,800 feet above sea level, while *lol* and *ll* are below sea level.

In a study of the results of this test example it is to be kept in mind that the given altitudes for poleward and equatorward positions, and those for *mo* midoptimum or centers of production as interpreted from positions on the maps, may vary considerably from the actual isophane and altitude limits. They serve, however, to illustrate the method of application, and to compare their variations with those of thermal records from the constants of appendix table 3, so that the results are at least suggestive of the limits and optima to be expected in each of the given regions.

Interpretations by Bioclimatic Zones

While the preceding methods of interpreting the altitude limits of wheat culture (example 13) and of finding the variations (examples 13 and 14) are (together with appendix table 11) available for securing the desired information, the simplest and most convenient method is by the bioclimatic zone or zonal-type principle, in which the period zonal type for any record or nonrecord position, area, or region, is determined by (*a*) the recorded average period between the seeding and harvest dates of winter wheat (example 3), or (*b*) the average *a* annual mean temperature (example 8).

According to this principle and method, it may be assumed that—other conditions being favorable for the culture of winter wheat—major zone II minor upper middle 3 (+.3) wherever found indicates the high isophane or upper altitude limit (*hl*) of commercial wheat culture; major II minor middle 4 (.4) indicates the *hol* high optimum limit; major II minor lower 4 (—4) indicates the *mo* midoptimum; major II minor lower 5 (—5) indicates the *lol* low optimum limit; and major II minor middle 6 (.6) indicates the *ll* low limit.

It may be assumed further that the zonal range of commercial wheat culture by isophane at, or altitude above, sea level will come between the upper middle zone 3 and middle zone 6; and that the optimum will come between middle zone 4 and lower zone 5, with the optimum center in or near lower zone 4.

TEST EXAMPLES BY CLIMATIC TIMBER-LINE CONSTANTS

DEFINITION OF CLIMATIC TIMBER LINE

Climatic timber line may be defined as the poleward sea-level or alpine altitude limit of upright growth of tree species, under otherwise favorable conditions, as distinguished from dwarf or prostrate forms of the same species, as controlled by the climatic elements of temperature, wind, snow, ice, etc.; and also as distinguished from limits of tree growth due to the absence of suitable soil, moisture, or the presence of local glaciers.

The observed and recorded timber line applies only in a broad way, because the recorded "line" for a given mountain may vary in width from a few feet to several hundred feet, while poleward at sea level the area in which it occurs may cover 1° or more of latitude. There is also a considerable difference in the altitude of the timber line on north, south, east, and west slopes or within local areas on the same mountain.

The ideal record, therefore, is that of a general average, based on observations at a number of places between the high and low extremes. Since, however, the ideal has not been, and cannot be, attained in this, as in so many other variable subjects, we must make the best use of the available facts and evidence, remembering (*a*) that there are no sharp lines of distinction in natural phenomena, (*b*) that in our studies and interpretation of results a certain range of error cannot be avoided, and (*c*) that a limited range of error is allowable in that it leaves a sound basis for general conclusions and application in the science and practice of bioclimatics.

MOST IMPORTANT ALTITUDE SUBJECT

Notwithstanding the range of error involved in dealing with the subject of climatic timber line, the altitude is the most important subject to be considered in applied bioclimatics for mountain and poleward regions, because it represents a conspicuous and more or less constant bioclimatic phenomenon as the effect of major and minor causes which have been in operation during a long period of geological time.

TIMBER-LINE CONSTANTS FOR SEA-LEVEL AND ALPINE POSITIONS

From available evidence and sources, the general average poleward sea-level limit of upright tree growth, allowing for modifications, would come in the Northern Hemisphere near isophane 57 on meridian 100 and in major zone II minor —1+2. It is assumed, therefore, that isophane 57, latitude 57, north or south on longitude 100 west or east represents a sufficiently reliable sea-level base position from which to compute a table of sea-level and altitude constants for both Northern and Southern Hemispheres.

TABLE OF TIMBER-LINE CONSTANTS

A table of altitude constants for climatic timber line is found in appendix table 10 under major zone II minor colimit —1+2, in which isophane 57 represents the sea-level base. Appendix table 3 or any table in which the zonal constants are given for the sea-level isophanes, shows that sea-level isophane 57 gives the colimit constant for minor zones —1+2. This signifies that wherever timber line occurs at sea level poleward, or above sea level equatorward, it represents the colimit of these minor zones.

Thus in accordance with the uniform system of coordinate requirement constants of bioclimatic law, and the basic principles of the *constant* and *variable* the record sea-level or alpine timber line of any geographic position referred to column —1+2 of appendix table 10 will give, by the corresponding altitude constant, the isophane equivalent index, which, when compared with the position isophane, will give its variation from the requirement constant in degrees of latitude; or, the record altitude, when compared with the altitude constant for the record position isophane, will give the variation of the record from its constant in feet.

EXAMPLE 15.[1]—*Selected list of record sea-level and alpine timber-line positions on the continents of the Northern and Southern Hemispheres*

SECTION A. SEA-LEVEL POSITIONS

pno	Region	*pl*	*plo*	*pi*	*par*	Isophane		Latitude	
						pc	*avx*	*pc*	*avx*
	North America:								
1	East	51.75	[2] 55	60.75	0	−1,500	+1,500	+2,100	−2,100
4	do	59.00	65	66.00	0	−3,600	+3,600	−800	+800
11	Central	69.25	124	64.50	0	−3,000	+3,000	−4,900	+4,900
15	West	60.00	162	47.50	0	+3,800	−3,800	−1,200	+1,200
16	do	66.50	162	54.00	0	+1,200	−1,200	−3,800	+3,800
	South America:								
5	West	46.50	[2] 73	[3] 41.25	0	+6,300	−6,300	+4,200	−4,200
	Eurasia:								
1	East	64.25	[4] 177	80.00	0	−9,200	+9,200	−2,900	+2,900
2	do	68.75	160	80.75	0	−9,500	+9,500	−4,700	+4,700
4	East central	71.00	128	76.50	0	−7,800	+7,800	−5,600	+5,600
7	Central	66.50	70	60.50	0	−1,400	+1,400	−3,800	+3,800
8	West	66.00	44	54.75	0	+900	−900	−3,600	+3,600
12	do	64.50	[2] 15	41.50	0	+6,200	−6,200	−3,000	+3,000

SECTION B. ALPINE POSITIONS

pno	Region	*pl*	*plo*	*pi*	*par*	Isophane *pc*	Isophane *avx*	Latitude *pc*	Latitude *avx*
	North America:								
29	West	46.75	[2] 121	42.50	6,000	5,800	+200	4,100	+1,900
7	Central	38.75	105	37.75	11,000	7,700	+3,300	7,300	+3,700
2	East	44.25	71	50.00	4,000	2,800	+1,200	5,100	−1,100
	Eurasia:								
21	West	46.00	[4] 9	27.75	6,300	11,700	−5,400	4,400	+1,900
5	Central average	33.50	87	31.00	14,000	10,400	+3,600	9,400	+4,600
1	East	35.25	138	42.75	6.000	5,700	+300	8,700	−2,700
	South America:								
1	West	[5] 4.00	[2] 76	[5] 8.75	14,000	19,300	−5,300	21,200	−7,200
2	do	[3] 9.25	77	[3] 4.75	15,000	20,900	−5,900	19,100	−4,100
4	do	[3] 1.25	78	[5] 2.25	15,600	21,900	−6,300	22,300	−6,700
	Africa:								
3	East	[3] 1.00	[4] 37	[3] 13.50	13,000	17,400	−4,400	22,400	−9,400
4	East central	[5] .50	30	[3] 13.50	12,000	17,400	−5,400	22,600	−10,600
5	West	[5] 4.00	9	[3] 14.25	8,100	17,100	−9,000	21,200	−13,100
7	North	[5] 36.00	4	[5] 16.75	5,500	16,100	−10,600	8,400	−2,900
	Java:								
1	Mount Slamet	[3] 7.00	109	[3] 5.50	9,200	20,600	−11,400	20,000	−10,800

[1] These position records are merely tentative, the object being to illustrate the principle and method.
[2] West.
[3] South.
[4] East.
[5] North.

Thus the variation in degrees of latitude, designated as the *lvx* latitude variation index, and the variation in feet, designated as the *avx* altitude variation index, are made available for interpreting the altitude for timber line within the general region represented by the record position, or by the average of any available number of record positions within a given region, as explained under example 15, in which *pno* gives the position numbers selected from a list of 28 sea-level and 76 alpine positions; *regions* the continents and other regions; *pl* the position latitude; *plo* the position longitude; *pi* the position isophane at sea level; and *par* the position altitude record of timber line at or above sea level. Under *isophane* and *latitude*, *pc* gives the position constant for *pi* or *pl* in table 10, column −1+2; and *avx* the altitude variation index of *par* from *pc*. The given *par* for sea level or above are as recorded for specific places, for the average of a number of places within the same region, or in some cases as interpreted from thermal indices, or from orographic or topographic maps on which the latitude or altitude limits of tree growth are shown. This example shows how the *avx* variations of the recorded or interpreted timber-line positions from their requirement constants are determined and made available for comparative study and further application by specialists on the subject who in the future will be equipped with more accurate and comprehensive information. In fact it is to be kept in mind that the position records given in this example and in the entire list from which they are taken are *merely tentative* and the results preliminary; the object being to illustrate the principle and method rather than to represent the facts.

The altitude constants of table 10 apply alike to the isophanes and latitudes of the given positions, but the constants for each differ as the numbers of the isophane and latitude of a given position differ on all meridians other than the one hundredth; e. g., in section A, North America 1, east *pl* 51.75° gives *pc* +2,100 feet above sea level, and *pi* 60.75 gives *pc* −1,500 feet below sea level, while North America 16 west *pl* 66.50° gives *pc* −3,800 feet below and *pi* 54.00 gives *pc* +1,200 feet above sea level. Thus, since timber line is recorded at sea level for both of these positions, the *avx* variation from the latitude requirement constant of +2,100 feet for North America 1 is −2,100 feet below the requirement constant, and from the isophane requirement of −1,500 feet it is +1,500 feet above the constant; while for North America 16 the *avx* is +3,800 feet higher than the latitude requirement, and from the isophane requirement −1,200 feet lower. The same relations of *avx* to *pc* apply in section B.

It will also be noted that, as applied to the variations, a minus variation indicates a colder influence and lower altitude, while a plus signifies a warmer influence and higher altitude than the constant. When the sign is not given for *pc*, it is above sea level.

CHARTED VARIATIONS

As in preceding isophane-latitude charts, the charted variations of timber line give a graphic picture of their relations to both the *isophane* and *latitude* requirements. Although not only the isophane and latitude of a given position east or west of the one hundredth meridian differ from each other in numerical designation but also the variations from each will differ, nevertheless, except when the position isophane is south of the equatorial isophane and the position latitude is north of it, or vice versa (examples 10 and 11), *the variation lines will have the same relation to the given requirement isophane and corresponding requirement parallel as they have to the isophane and latitude of any given position on any other isophane.* This is because the constants of the table from which the variations are determined have the same coordinate relation from the equatorial to the polar isophanes, so that no matter how much difference there may be between the number of a given position isophane and that of a given requirement isophane, or how far the position may be from the given requirement isophane or parallel, the relation of the variation to the position isophane or position latitude will be represented by the variation line relative to the given requirement isophane and requirement parallel.

In the equatorial region, represented by sections E and F of figure 24, the relations of the variations for the isophane and latitude will differ as the north and south isophane and latitude of the given position differ; when the position isophane is north of the equatorial isophane 0 and the latitude of the same position is south of the Equator, or vice versa, the relations of the variations to both cannot be represented on the same chart and, therefore, are represented as relative to the isophane alone.[16]

[16] When the isophane position is south of the 0 isophane, the minus variation will be north-poleward above the requirement isophane, while the plus variation will be south-poleward below it. While if the latitude of the same position is north, its minus variation will be south-poleward below the requirement parallel and its plus variation will be north-poleward above the requirement parallel.

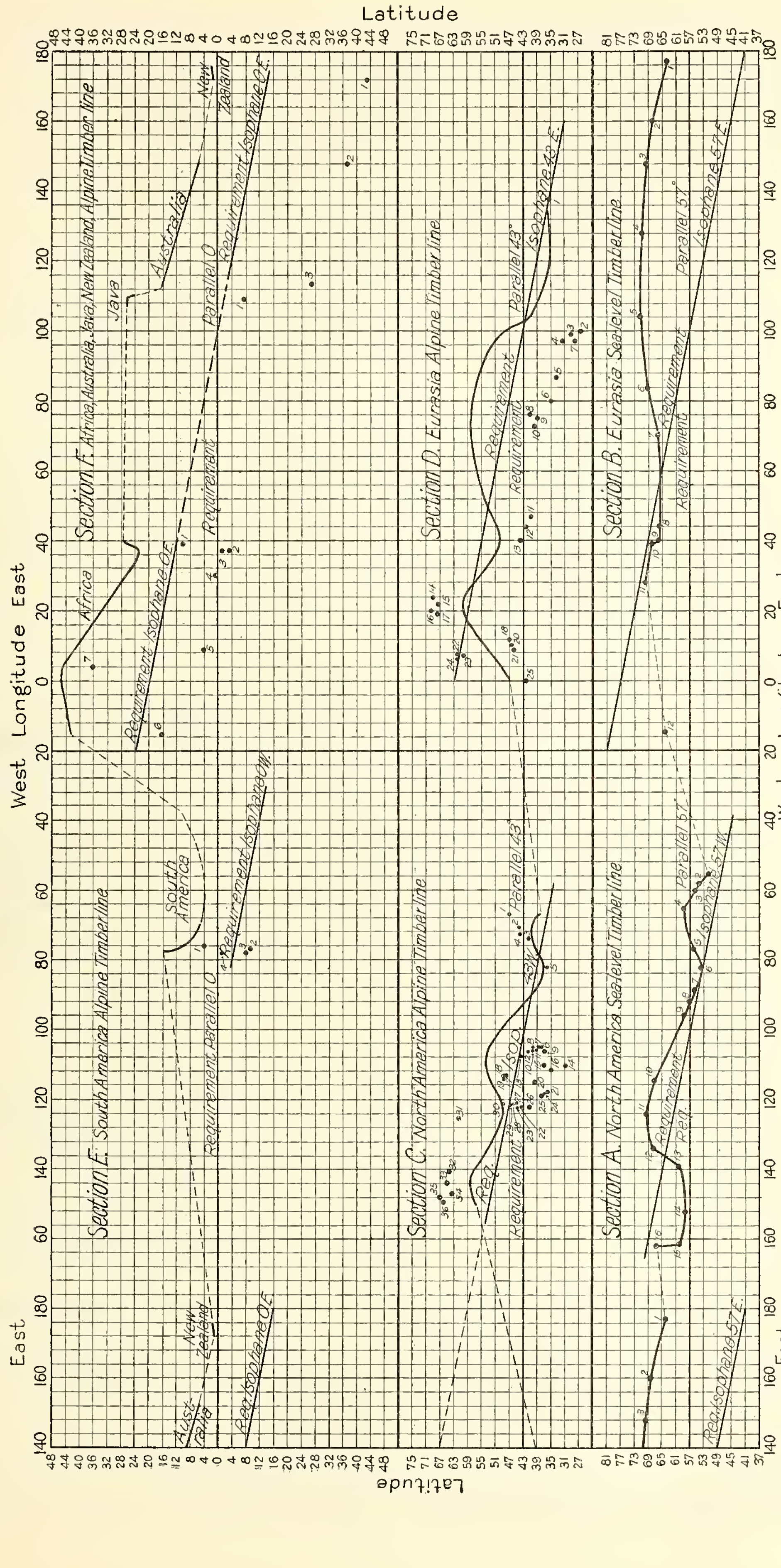

FIGURE 24.—Variation lines for sea-level and alpine timber line relative to the isophane and latitude requirement constants of appendix table 10.

In figure 24 in sections A and B the record positions of sea-level timber line agree with the positions of the variations as shown in example 15, because for sea-level positions the *avx* is always the same number of feet as the altitude constant, but with the plus and minus signs reversed. Thus the altitude constant for North America position 1 is −1,500 below the *pi* 60.75, and since the record is at sea level on isophane 60.75, the altitude variation from the *pi* is +1,500 feet above the isophane requirement constant of −1,500, as shown; and in a like manner the altitude variation from the *pl* is −2,100 feet below the latitude requirement constant of +2,100 feet, as shown. In figure 24 the designated parallels of latitude are given at intervals of 4°, representing an equivalent altitude of 800 feet to 2°, by which the determined variation for each position is measured from the given requirement isophane and requirement parallel across the continents.

In sections C to F, where all the recorded timber-line positions are above sea level, the positions (dots and numbers) as shown on the chart may be on, near, or far away from the given requirement isophane or parallel, but the relations of their variations from their *pi* and *pl* constants are correctly represented on the chart by the same variation in feet from the requirement isophane and parallel, so that the variation line is a reasonably accurate representation of the trend of the variations from the timber-line constants of all record positions across the continents and at the same time plainly indicates the relative intensity of the major modifying influences in causing a higher or lower timber line from the requirements of the bioclimatic and astronomic law.

The smoothed variation lines across the continents give a general picture of (1) the general average trend of the variation line for *poleward sea-level timber line* of the Northern Hemisphere (secs. A and B) with reference to the requirement isophane and requirement parallel 57, within a range of about 17.50° of latitude across North America and about 7.75° across Eurasia; (2) the general average variation of *alpine timber line* of the Northern Hemisphere with reference to the requirement parallel and isophane 43 across North America (C) within a range of 35.75° between latitude 67 in Alaska and 31.25 near the Arizona and Mexico border, and across Eurasia (D) within a range of 44° between latitude 70 in Scandinavia and 26 in Tibet; and (3) the general average variation of alpine timber line of the equatorial region with reference to the requirement parallel and isophane 0 across South America (E) within a range of 13.25° of latitude between isophane 4 north in Colombia and 9.25 south in Peru, and across New Zealand, Australia, Java, and Africa (F) within a range of 79° between 43 south in New Zealand and 36 north in Algeria.

METHOD OF PROCEDURE

The method of procedure to locate the positions and find the average position of the variation relative to the requirement latitude and isophane is to utilize cross-section paper with intervals to represent 2° of latitude and longitude to 0.1 inch, or 20° to the inch, with an equivalent of 800 feet of altitude for each 2° of latitude or isophane.

The record positions are then located by latitude and longitude and marked by a dot and the list number. The positions on the charts of the variations from the requirement isophane are then determined by the *avx* for each position (as in example 15) measured in feet (fig. 11) from the requirement isophane and marked by a dot on the position meridian. When the position of the variations has been marked for all of the record positions relative to a given requirement isophane they are connected by straight lines which are then smoothed. The smoothed line thus represents a general average relation of the variations for each position to both the requirement isophane and requirement parallel across the given regions.

For the continental areas north, represented by sections A, B, C, and D, the variation lines above and north-poleward from the requirement isophane signify a warmer climate and higher altitude for timber line, while the line below the requirement isophane south-poleward or equatorward signifies a colder climate and lower altitude than that represented by the requirement constant for the record position. For the equatorial regions E and F between about isophane 8.75 N. in South America, 16.75 N. in Africa, and 28.50 S. in New Zealand, the variations north-poleward or equatorward are all minus and colder with lower altitude than the isophane or latitude requirement, but where the latitude positions are north of isophane 0, as in positions 1 in South America and 7 in Algeria, the variation line represents the variation from the position isophane alone.

POSITIONS FOR SEA-LEVEL TIMBER LINE

Section A

1. North shore of Belle Isle Strait, Labrador.
2. Hamilton Inlet, Labrador.
3. Hopedale Mission, Labrador.
4. Shores of Ungava Bay or near mouth of George River.
5. East shore of Hudson Bay and Richmond Gulf.
6. West shore of James Bay or mouth of Opinnagow River.
7. West shore of Hudson Bay near Severn Fort, or Severn River.
8. Near York Factory.
9. Near Fort Churchill.
10. South shore of Coronation Gulf near mouth of Coppermine River.
11. South shore of Arctic Ocean and Franklin Bay.
12. Mackenzie Delta.
13. Shores of Yakutat Bay.
14. Shore of Shelikof Strait and Afognak Island.
15. Shore of Kuskokwim Bay.
16. North Shore of Kotzebue Sound, Alaska.

Section B

1. Shore of Anadyr Bay, Siberia.
2. Near mouth of Kolima River, Siberia.
3. Near mouth of Inaigirka River, Siberia.
4. Near mouth of Lena River, Siberia.
5. Near mouth of the Khatanga River, Siberia.
6. Near mouth of Yenisie River, Siberia.
7. Near mouth of the Ob River, Siberia.
8. Near the mouth of the Mesen River, Union of Soviet Socialist Republics.
9. Shore of the White Sea, Union of Soviet Socialist Republics.
10. Mouth of Jokanka River, Lapland.
11. Near Tana Fjord and Tana River, Norway.
12. Shores of Iceland.

POSITIONS FOR ALPINE TIMBER LINE

Section C

1. Bald Mountain, New Brunswick.
2. Mount Washington, New Hampshire.
3. Catskill average, New York.
4. Mount Marcy, New York.
5. Mount Mitchell, North Carolina.
6. Sangre de Cristo, Colorado.
7. Pikes Peak, Colorado.
8. Longs Peak, Colorado.
9. Conejos Peak, Colorado.

10. Mount Berry, Colorado.
11. Average of 10 peaks, all in Colorado.
12. Medicine Bow, Wyoming.
13. Big Horn Mountains, Wyoming.
14. Near Arizona and Mexico line.
15. Northern Arizona.
16. San Francisco Mountains, Arizona.
17.
18. Northern Montana.
19.
20. Southern Sierra Nevada, California.
21. Mount Whitney, California.
22.
23. Cascade Mountains, Oregon.
24.
25. Sierra Nevada, California.
26. Mount Shasta, California.
27. Mount Hood, Oregon.
28. Mount Adams, Washington.
29. Mount Rainier, Washington.
30. Mount Baker, Washington.
31. Canada.
32.
33.
34. Alaska.
35.
36.

Section D

1. Fuji Yama, Japan.
2.
3.
4.
5. Himalaya Mountains, with 5 representing the average.
6.
7.
9.
10.
8. Tian Shan, China.
11.
12. Caucasus Mountains, with 12 as the average.
13.
14.
15. Scandinavia north, with 14 as the average.
16.
17.
18. Austrian Alps average.
20. Ortler Alps, Italy, average.
21. Swiss Alps average.
22.
23. Southern Scandinavia.
24.
25. Pyrenees, France, average.

Section E

[By isophane and latitude]

1. Colombia, both north.
2.
3. Peru, both south.
4. Mount Chimborazo, Ecuador, isophane north, latitude south.

Section F

[By isophane and latitude]

1. New Zealand Alps, both south.
2. Australian Alps, both south.
3. West coast (thermal equivalent), both south.
1. Mount Slamet, Java, both south.
1. Abyssinia (thermal equivalent), isophane south, latitude north.
2. Kilimanjaro, both south.
3. Mount Kenya, both south.
4. Mount Ruwenzori, isophane south, latitude north.
5. Cameroon, isophane south, latitude north.
6. West coast (thermal equivalent), isophane south, latitude north.
7. Atlas Mountains, both north.

The thermal equivalents are the interpreted altitudes based on thermal variations for thermal record positions within the given local regions.

Example 16.—*Interpretation of timber line by the altitude-variation index and by the latitude-variation index*

SECTION A

	To find the *avx*					To find the *lvx*			
	pi	*plo*	*par*	*ac*	*avx*	*pi*	*par*	*iex*	*lvx*
N. A. sea level:									
4. E	66.00	65	0	−3,600	+3,600	66.00	0	57.00	−9.00
9. C	59.75	94	0	−1,100	+1,100	59.75	0	57.00	−2.75
16. W	54.00	162	0	+1,200	−1,200	54.00	0	57.00	+3.00
N. A. alpine:									
2. E	50.00	71	4,000	2,800	+1,200	50.00	4,000	47.00	−3.00
7. C	37.75	105	11,000	7,700	+3,300	37.75	11,000	29.50	−8.25
26. W	37.00	122	8,000	8,000	0	37.00	8,000	37.00	.00

SECTION B

	Interpretation by *avx*				Interpretation by *lvx*				
	pi	*ac*	*avx*	*par*	*pi*	*lvx*	*iex*	*par*	*tl* zone
N. A. sea level:									
4. E	66.00	−3,600	+3,600	0	66.00	−9.00	57.00	0	II−1+2
9. C	59.75	−1,100	+1,100	0	59.75	−2.75	57.00	0	−1+2
16. W	54.00	+1,200	−1,200	0	54.00	+3.00	57.00	0	−1+2
N. A. alpine:									
2. E	50.00	+2,800	+1,200	4,000	50.00	−3.00	47.00	4,000	−1+2
7. C	37.75	+7,700	+3,300	11,000	37.75	−8.25	29.50	11,000	−1+2
26. W	37.00	+8,000	0	8,000	37.00	.00	37.00	8,000	−1+2

INTERPRETATION OF TIMBER LINE FOR NONRECORD POSITIONS BY THE ALTITUDE OR LATITUDE VARIATION INDEX

The principle and method of interpreting timber line for nonrecord positions by the altitude or latitude variation index are the same as previously described, in that the determined *avx* of a representative record position plus or minus the altitude constant for the nonrecord position isophane gives the interpreted altitude of timber line for it, or the determined *lvx* of a record position plus or minus the *pi* for the nonrecord position will give the *iex*, which in table 10 gives the interpreted altitude for the position, as shown in example 16, which shows how the *avx* and the *lvx* are determined and applied to the position numbers from example 15 or the general list.

In example 16 the *avx* and *lvx* are relative to the isophane requirements alone for application in the interpretation of timber line for nonrecord isophane positions within the range of the same (or similar) modifying influences as those represented by the variations of a record position or a number of record positions within a local area or region; the altitude variation is applied to the nonrecord *ac* position altitude constant and the latitude variation is applied to the position isophane of the nonrecord position, as previously described in section B. Thus the *avx* plus or minus the *ac* of any nonrecord position gives the interpreted altitude, and *lvx* plus or minus the *pi* of any nonrecord position will give the interpreted isophane equivalent index, which referred to table 10 will give the interpreted altitude.

The great importance and significance of these methods of interpreting the timber line is in the fact that with either the *avx* or *lvx* known for a given position the approximate corresponding sea-level or alpine position can be interpreted for any place where timber line may occur within the range of the same or similar modifying influences.

INTERPRETATION BY THE TIMBER-LINE ZONE

As in the interpretation of altitude limits for winter wheat culture, it may be safely assumed that wherever

major zone II minor −1+2 occurs, as determined by the record *a* annual mean of appendix table 3, thermal conditions will influence the corresponding climatic timber line although the altitude may be more or less modified by the *w* and *c* zonal types.

GENERAL AVERAGE VARIATION LINES FOR THE NORTHERN AND SOUTHERN HEMISPHERES

A general average for the determined variations of recorded timber-line positions from the isophane constants of appendix table 10 may be shown by the triangular chart method, as in figure 25, in which the one hundredth meridian of the Northern and Southern Hemispheres is taken to represent a general average or hypothetical sea-level base line from the north pole (N. P.) to the south pole (S. P.). The north and south timber-line constant lines represent the variations of the records from their constants for each isophane. Thus the broken line, *highest*, represents the plus and warmer variations and *lowest* the minus and colder variations from the isophane requirement constant line north and south, while the continuous line represents the *general average* variation from sea level north at about isophane 59 to the highest altitude of 15,500 feet at about isophane 15 north, and at about 14,400 feet above the Equator, to sea level at about isophane 42 south.

The interpreted high, low, and average altitude of timber line for positions at or near any given isophane are determined by the intersection of the variation line with the vertical isophane lines and the horizontal altitude line.

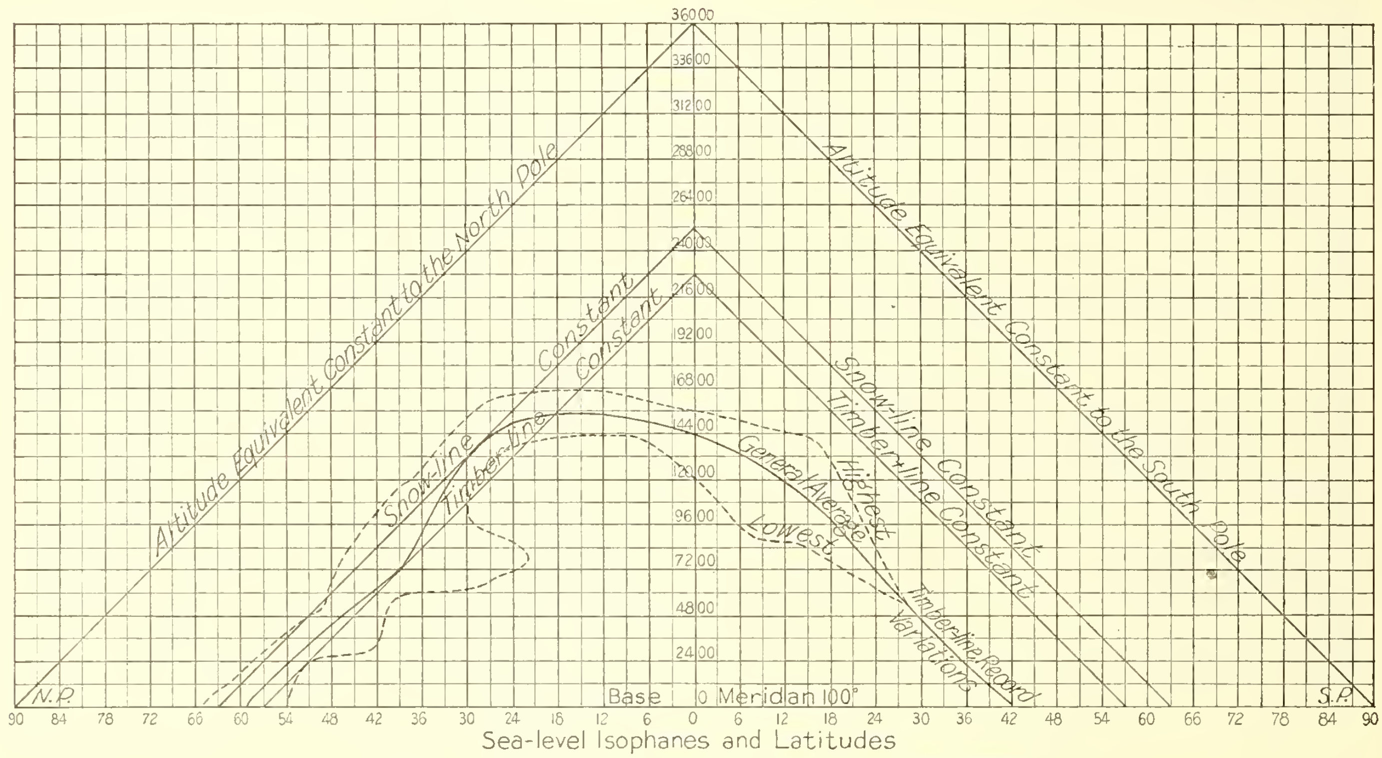

FIGURE 25.—Average variation of timber-line records from the requirement constants.

isophanes and latitudes (of equal number on this meridian) are represented by vertical isophane-latitude lines at intervals of 6°; and the vertical altitude constant and horizontal altitude lines above the equatorial isophane 0 are given at intervals of 2,400 feet from 0 at the poles to 36,000 feet above sea level on the Equator. The oblique lines represent altitude equivalent constants above the given sea-level isophanes as sea level at the *N. P.* and *S. P.* isophanes 90, to 24,000 feet on isophane 30 and to the highest altitude constant of 36,000 feet on the Equator, with each altitude for a given isophane being equivalent to sea level at the poles. The lines from sea-level isophane 63 north and south to 25,200 feet above the Equator represent the altitude constants for snow line above sea level on each isophane; and the lines from sea level on isophane 57 north and south to 22,800 feet above sea level on the Equator represent the altitude constants for timber line above sea level on each isophane.

The *lowest*, *highest*, and *general average* recorded altitudes of timber line are represented by the smoothed broken and continuous lines, and their distance from the

OUTSTANDING FEATURES OF THE VARIATIONS FROM SEA-LEVEL TIMBER-LINE CONSTANTS

Some of the outstanding features of figure 24 are the wide plus or warmer departures from the requirements of both bioclimatic and astronomic law across Asiatic Siberia for positions 1 to 7 in section B. Thus, notwithstanding the fact that parts of this region have lower temperatures than the extreme polar regions, there is an extension of tree growth further north than in northern Europe or North America where the minimum temperature is much higher. This is to be explained in part at least by the extreme *wac* continental type of climate in Siberia, in which there is a range between the lowest temperature of −50° F. or more for the coldest month and the highest of +50° or more in summer for the warmest month, with the mean for June, July, and August of 40° or more; so that while the extreme cold would seem to prohibit tree growth, the relatively warm summers favor it. Moreover, the tree species, principally spruce, are sufficiently hardy in their dormant stage to survive the extreme cold.

In comparing the temperatures of Siberia with the lowest and highest temperatures in northern Europe and North America at or near the sea-level limit of tree growth, we find that in North America the lowest average temperature for the highest position (11) on Franklin Bay, as indicated by the January isotherm, is about −30° F., with a temperature of about 40° in July, while for northern Norway the lowest is about 10° and the highest about 50°. It is evident, however, that there are factors other than summer temperature to cause the high limits in Siberia, because there is scarcely enough difference in summer temperature alone to account for it.

The extension from North America (sec. A, 16) of this high limit of sea-level timber line across the greater part of Siberia (1 to 6) is another striking feature, as is also the nearly normal variation from the isophane of the extreme westward position 11 in Norway; while on the coast of Iceland (Eurasia 12) the variation is nearly (−6,200) as far below the requirement isophane as it is above it (+9,200) at Anadyr Bay (Siberia 1) in nearly the same latitude.

The striking features of the variations from the latitude requirements across North America are the low variations of −1,200 to −2,100 feet on the east coast as compared with the relatively high variations of +1,200 to +3,800 feet near the west coast of Alaska, while the relations relative to the isophane requirements are reversed.

TREND OF THE VARIATIONS

It will be noted that the sea-level variation line across Eurasia (fig. 24, *B*) is far above the latitude and isophane requirements for parallel 57 and isophane 57, from positions 1 to 7 and above the latitude requirement to position 11, and more nearly in accord with astronomic law although there is a marked variation from the latitude requirement. It is significant, however, that from positions 7 to 11 the variation line agrees very closely with that of the isophane requirement. Across the Atlantic Ocean between Eurasia 11 in Norway and 12 in Iceland, and on to North America 1 in Labrador, the trend is strongly southwestward and thus (as usual with other subjects) is in opposition to both bioclimatic and astronomic law as applied to the continents.

Across North America (fig. 24, *A*) the trend relative to isophane 57 W is more nearly in accord with bioclimatic law, especially from positions 1 to 12 and 16 on the west coast of Alaska, across Behring Strait to Eurasia 1 on the east coast of Siberia, and on to Eurasia 5, in close agreement with an extension of isophane 57 W across Siberia.

THE MORE SIGNIFICANT FEATURES

For North America and Eurasia (fig. 24, *C* and *D*) the outstanding features of the alpine timber line are (1) the close agreement of the trend of the variation lines with the requirements of bioclimatic law across both continents; (2) the marked plus warmer variations across the Himalayas, near normal for Scandinavia north, positions 14 to 17, and the marked minus cold variations for the Alps, 18 to 21, and especially for the Pyrenees, 25; (3) the southwestward trend across the Atlantic and Pacific Oceans; and finally (4) the northwestward trend across North America and its extension across the Pacific Ocean to connect with the variation line for position 1 in Japan.

For South America, New Zealand, Africa, and Australia (fig. 24, *E* and *F*) the outstanding features are in the prevailing minus cold and lower altitude variations from both the isophane and latitude requirements, with extremes in Java and on the northwest coast of Africa and in western South America. Here again the general trend of the variation line across the continental and insular areas is more nearly with the isophanes than with the parallels.

The outstanding features of the general average variation (fig. 25) relative to isophane requirements for continental areas are (1) the near normal minus and plus in average variations and trend from sea level on isophane 59 to about isophane 15 for the Northern Hemisphere; (2) the extreme minus cold variation across the central tropical regions between about isophane 15 N. and 15 S. and on to sea level in isophane 42 S., with a quite uniform minus variation of about 6,000 feet from isophane 12 to 42 south, thus presenting further conclusive evidence of an extreme modifying influence for the southern continents.

In the preceding test examples, by time, thermal, and distance subjects it will be noted that there is a remarkably close general agreement in the trend of the variation lines relative to the given requirement isophanes across the same major regions and continents, with the same marked reversal in trend across the oceans.

The evidence brought out in the examples (fig. 24, *A* and *B*) would seem to indicate that if land were continuous from the west coast of North America across the North Pacific there would be a profound difference in the climate of northern Eurasia; and, as indicated by the same evidence, if there were continuous land from western Europe across the North Atlantic and North America to Alaska, one can readily conceive that, according to bioclimatic law, subtropical conditions might occur in northwestern North America, as they did in geological time.

IMPORTANCE OF TIMBER LINE AS AN INDEX TO THE COLIMITS OF BIOCLIMATIC ZONES

As will be shown in part 2 under interpretation of zones by the timber-line index for polar and mountain regions, the timber-line index is of fundamental importance in bioclimatics because it furnishes evidence of the effect of a longer period of influence of the causation complex of a polar or mountain region than does any other subject, and therefore it must be the most reliable index and guide to the interpretation of its zones and the related phenomena.

APPLICATION OF BIOCLIMATICS IN A STUDY OF SPECIAL REGIONS

Now that we have considered the general principles, systems, and methods of procedure in applied bioclimatics with test examples of principles and methods by time, temperature, and distance records, as related to the continents, in this section we shall discuss applications to special regions.

THE ALPS REGION

The Swiss and Austrian Alps serve as a typical example to show how bioclimatics can be applied to a distinctive region in a comprehensive study and analysis of its biologic, climatic, seasonal, and economic features. In many respects this region is ideal for such a test because it is on another continent from that of the intercontinental base and is representative of western Europe with its extreme western coast and

mountain types of climate, showing marked departures in its thermal, time, and distance records from the requirement constants of bioclimatic law. It is also ideal in that it is represented by temperature, time, and altitude records taken over a period of time long enough to furnish a basis for comprehensive studies.

Phenological time records are represented by dates of wheat harvest; the awakening of vegetation; blooming of cherries; hay harvest; ripening of cherries, winter wheat, and oats; and the beginning of winter.

The distance records include many altitude positions of timber line and snow line and at least one record of the high-altitude limit of wheat culture.

SELECTED POSITIONS

Out of the many record positions, seven thermal and seven wheat-harvest positions are selected as representative of the region; these, together with the average altitude of timber line and high limit of wheat culture, serve as ideal bases for this study.

EXAMPLE 17.—*List of record positions with thermal records and variations*

pno	Position	*pi*	*pl*	*plo*	*pa*	Equivalents		Records ° F.			*lvx* variations		
						le	*ei*	*a*	*w*	*c*	*a*	*w*	*c*
1	Santis	29.00	47.25	9	8,200	20.50	49.50	27.3	41.0	16.1	+10.75	+23.50	+0.50
2	Rigi Kulm	28.75	47.00	8	5,800	14.50	43.25	35.6	49.8	23.9	+11.50	+22.25	+2.75
3	Sils Maria	28.25	46.25	9	5,900	14.75	43.00	34.7	52.1	17.4	+12.50	+20.25	+7.25
4	Zurich	29.00	47.25	8	1,500	3.75	32.75	47.3	65.1	29.4	+16.50	+21.25	+13.25
5	Berne	28.25	46.75	7	1,900	4.75	33.00	46.5	64.4	28.4	+16.75	+21.50	+13.75
6	Geneva	27.25	46.00	6	1,300	3.25	30.50	48.9	66.0	32.1	+17.50	+22.50	+13.75
7	St. Bernard	27.25	45.75	7	8,100	20.25	47.50	28.9	43.8	16.3	+11.50	+22.75	+2.25
8	Average	28.25	46.50	8	4,700	11.75	40.00	----	----	----	+14.00	+22.00	+7.75

EXAMPLE 18.—*Latitude-variation indices, isophane-equivalent indices, zones, and zonal types for positions in example 17*

pno	*ei*	*a* mean			*w* mean			*c* mean		
		lvx	*iex*	*zone*	*lvx*	*iex*	*zt*	*lvx*	*iex*	*zt*
1	49.50	+10.75	60.25	1−4	+23.50	73.00	1 +.3	+0.50	50.00	11 +.3
2	43.25	+11.50	54.75	11 .2	+22.25	65.50	+.4	+2.75	46.00	.4
3	43.00	+12.50	55.50	+.2	+20.25	63.25	.4	+7.25	50.25	+.3
4	32.75	+16.50	49.25	.3	+21.25	54.00	11 .2	+13.25	46.00	.4
5	33.00	+16.75	49.75	.3	+21.50	54.50	.2	+13.75	46.75	+.4
6	30.50	+17.50	48.00	−3+4	+22.50	53.00	.2	+13.75	44.25	−.4
7	47.50	+11.50	59.00	+.1	+22.75	70.25	1 .3	+2.25	49.75	.3
8	40.00	+14.00	54.00	.2	+22.00	62.00	1 .4	+7.75	47.75	+4
Zonal constants for *ei 40.00*	-----	------	----	−5+6	------	----	11−5+6	------	------	11−5+6

Examples 17 to 24 give the essential information and methods of finding the *lvx* latitude variations and *iex* isophane equivalent indices, either of which provides a key to the interpretation of some of the outstanding bioclimatic features of the region, including the zones, zonal types, and climatic types as represented by the record positions and their averages, with special reference to the intercontinental requirement constants of bioclimatic law. The principles and methods have been previously discussed, but a few features deserve especial attention.

Example 18 shows how the *iex* is determined for each position and the average, as *ei* plus *lvx* in example 17 equals *iex,* which referred to table 3 gives its *a* zone and *w* and *c* zonal types for each position and the average. It will be noted that the *a* and *c lvx* variations are all higher and colder, and that the *w* variation is very much higher than the requirements; consequently the zones and types are much higher than those of the position and average constants, as clearly shown by the zonal constants for the average *ei* 40. All this clearly shows that the region is on the average for the year colder than the requirement constant, with the summers much colder, but with the *c* variations relatively warmer than the *w* variations.

EXAMPLE 19.—*List of record positions with records of winter wheat harvest dates and variations*

pno	Positions	*pi*	*pl*	*plo*	*pa*	Equivalents		Records			Variations		
						le	*ei*	*pr*	*pr*	*pc*	*dvx*	*lvx*	*iex*
								md	*yd*	*yd*			
1	Schaffhausen.	29.25	47.50	8	1,300	3.25	32.50	July 4	185	126	+59	+14.75	47.25
2	Mettmenstetten.	28.75	47.25	8	1,600	4.00	32.75	July 10	191	127	+64	+16.00	48.75
3	Zurich	29.00	47.25	8	1,600	4.00	33.00	July 19	200	128	+72	+18.00	51.00
4	Malaus	28.75	46.75	9	1,800	4.50	33.25	July 2	183	129	+54	+13.50	46.75
5	Lutzelfluh	28.50	47.00	7	2,200	5.50	34.00	Aug. 8	220	132	+88	+22.00	56.00
6	Berne	28.25	46.75	7	1,900	4.75	33.00	July 16	197	128	+69	+17.25	50.25
7	Geneva	27.25	46.00	6	1,300	3.25	30.50	July 4	185	118	+67	+16.75	47.25
8	Average	28.50	47.00	8	1,700	4.25	32.75	July 13	194	127	+67	+16.75	49.50

EXAMPLE 20.—*Average altitude of timber line, with variations from requirements*

pi 28.50, *pr* 6,300, *pc* 11,400, *avx* −5,100 ÷ 400, *lvx* +12.75 + *pi iex* 41.25 for *pr* in table 10.

EXAMPLE 21.—*Record altitude high limit for winter wheat average, culture, with variations from requirements*

pi 29.50, *pr* 5,500, *pc* 8,200, *avx* −2,700 ÷ 400, *lvx* +6.75 + *pi*, *iex* 36.25 for *pr* in table 11.

EXAMPLE 22.—*Comparison of thermal, time, and distance average variations, zones and zonal types (examples 18 to 21)*

Ex.	*pno*	Subject	*Sym*	*pi*	*ei*	*lvx*	*avx*	*iex*	Table	*Ma Mi*
18	8	Thermal	*a*	28.25	40.00	+14.00	−5,600	54.00	3	11 .2 *a* zone.
18	8	do	*w*	28.25	40.00	+22.00	−8,800	62.00	3	1 .4 *w* type.
18	8	do	*c*	28.25	40.00	+7.75	−3,100	47.75	3	11 +4 *c* type.
19	8	Time	*WW H*	28.50	32.75	+16.75	−6,700	49.50	7	11 .3 *H* type.
20	----	Distance	*tl*	28.50	-----	+12.75	−5,100	41.25	10	II−1+2 *tl* zone.
21	----	do	*WW hl*	29.50	-----	+6.75	−2,700	36.25	11	11 +.3 *hl* zone.

Example 22 Gives comparisons of thermal, time, and distance averages of *pi, ei, lvx, avx, iex,* and major and minor zones and types for positions 8 in examples 18 and 19, and for examples 20 and 21. It will be noted that there is a fairly close agreement between the variations of the *a* annual mean, the *w* warm mean, *WW H* winter wheat harvest date, and *tl* timber line, and between that of the *c* cold mean and *WW hl* winter wheat high limit altitude. All this shows a marked cold departure from the requirement constants in the plus higher and colder *lvx* and in the lower and colder *avx,* which are referred to further on in the comparison between intercontinental and continental variations (examples 25, 26, and 27).

Example 23 shows the coordinate equivalents of the variations for thermal, time, and distance, and the zones and types represented by the seven specific positions and averages in examples 17 to 21, in which the *dvx* day variation index is *lvx* × 4 days to 1° and the *avx* is *dvx* × 100 feet to 1 day; all of which shows a decided colder variation from the intercontinental requirements which is found to apply in general to all of western Europe.

EXAMPLE 23.—*Variation indices in equivalent latitude, days, and feet, and isophane-equivalent indices, zones, and zonal types*

Position nos.	1	2	3	4	5	6	7	Remarks
Ex. 17 *a lvx*	+10.75	+11.50	+12.50	+16.50	+16.75	+17.50	+11.50	poleward colder.
a dvx	+43	+46	+50	+66	+67	+70	+46	later colder.
a avx	−4,300	−4,600	−5,000	−6,600	−6,700	−7,000	−4,600	lower colder.
Ex. 18 *a iex*	60.25	54.75	55.50	49.25	49.75	48.00	59.00	poleward colder.
a z	1 −4	II .2	+.2	.3	.3	−3+4	+.1	higher colder.
Ex. 19 *H lvx*	+14.75	+16.00	+18.00	+13.50	+22.00	+17.25	+16.75	poleward colder.
H dvx	+59	+64	+72	+54	+88	+69	+67	later colder.
H avx	−5,900	−6,400	−7,200	−5,400	−8,800	−6,900	−6,700	lower colder.
H iex	47.25	48.75	51.00	46.75	56.00	50.25	47.25	poleward colder.
H zt	11 +4	−.3	−2+3	+.4	+2	+.3	+4	higher colder.

	Averages				Grand average	Remarks
	Ex. 20 *tl*	Ex. 21 *hl*	Ex. 17 *a*	Ex. 19 *H*		
lvx	+12.75	+6.75	+14.00	+16.75	+12.50	poleward colder.
dvx	+51	+27	+56	+67	+50	later colder.
avx	−5,100	−2,700	−5,600	−6,700	−5,000	lower colder.
iex	41.25	36.25	54.00	49.50 (17, 19)	51.75	poleward colder.
z	11−1+2	11+.3	II .2	*zt*II .3	II −2	higher colder.

EXAMPLE 24.—*Interpretations for nonrecord positions*

Thermal	Ex.	*pno*	*ei*	*lvx*	*iex*	Table	*rec.*	*Ma. Mi.*
Record position:								
a annual mean	17	5	33.00	+16.75	49.75	3	46.5	II .3 zone.
w warmest month	17	5	33.00	+21.50	54.50	3	64.4	.2 type.
c coldest month	17	5	33.00	+13.75	46.75	3	28.4	+.4 type.
Nonrecord position:								
a annual mean	----	----	40.00	+16.75	56.75	3	37.8	+2 zone.
w warmest month	----	----	40.00	+21.50	61.50	3	57.5	I −.4 type.
c coldest month	----	----	40.00	+13.75	53.75	3	17.8	II .2 type.
Wheat harvest:								
Record position	19	6	33.00	+17.25	50.25	7	197	+.3 type.
Nonrecord position	----	----	34.00	+17.25	51.25	7	201	−2 type.
Timber line:			*pi*					
Record position	20	----	28.50	+12.75	41.25	10	6,300	−1+2 zone.
Nonrecord position	----	----	29.00	+12.75	41.75	10	6,100	−1+2 zone.
Winter wheat high limit:								
Record position	21	----	29.50	+6.75	36.25	11	5,500	+.3 zone.
Nonrecord position	----	----	28.50	+6.75	35.25	11	5,900	+.3 zone.

Example 24 shows how the *lvx* of a record position is utilized to interpret the thermal, time, or distance record and zone and type for nonrecord positions, in which for thermal and time subjects *ei* plus *lvx* of the nearest record position gives the *iex*, which referred to table 3 gives the interpreted *a* mean and zone and *w* and *c* means and zonal types; or which, if referred to table 7, gives the interpreted winter wheat harvest date and zonal type for the nonrecord position. Thus the *lvx* for any record position (or the average of the record positions of a region) applies to the *ei* of any nonrecord position within the local area represented, so that by this principle and method detailed interpretations can be made for places within an entire local area or region.

This principle and method also apply to the interpretation of timber line and the high-altitude limit of winter wheat culture, except that the *lvx* for a local area or region is applied to the *pi* of the nonrecord positions; e. g., in example 24 nonrecord *pi* 29.00 + *lvx* 12.75 (in example 20) gives *iex* 41.75, which, referred to table 10, gives the interpreted timber line at 6,100 feet; and nonrecord *pi* 28.50 + *lvx* 6.75 (in example 21) gives *iex* 35.25, which in table 11, gives interpreted high-altitude limit of winter wheat at 5,900 feet; and so on for any number of positions within the area or region represented by the record latitude variation index.

REVIEW

These examples serve to illustrate the principles and methods of acquiring the necessary preliminary information to serve as a basis for the interpretation of the major bioclimatic features of the Swiss Alps as related to the intercontinental base of eastern North America and the requirement intercontinental constants computed from it, in that for the isophane and latitude of the region (1) a decided colder average condition is indicated by the variations of all subjects for all of the record positions; (2) an extreme mountain and western coast (*caw*) type of climate is indicated by the relations between the *a*, *w*, and *c* latitude variation indices of example 17 in which *c* is warmer and *w* cooler than the *a* variation, and all are relatively cool as related to the requirement constants for the isophanes; (3) the extreme retardation of the development and ripening of wheat is indicated by the later harvest dates than the requirement constants in example 19; and (4) an extremely low altitude of climatic timber line is shown in example 20, and a very low altitude for the high limit of wheat culture in example 21. Furthermore, the marked colder variation in latitude degrees, the later dates, the lower equivalent altitude variations and altitude records of timber line and limit of wheat culture (as shown in example 23), the grand average for all positions and subjects, and the marked higher zones and zonal types as compared with the average requirement zonal constants (as seen in examples 18, 22, and 23) all indicate an extreme western coast and mountain type of climate relative to the intercontinental constants.

INTERCONTINENTAL, CONTINENTAL, REGIONAL, AND LOCAL VARIATIONS

While the intercontinental constants and variations serve the primary purpose of indicating the relative intensity of the continental influences relative to the intercontinental base, as shown in the preceding examples, it is often desirable to determine separately the intensity of regional and local influences relative to a continental, regional, or local base.

This is accomplished, and the coordination of the system of constants and principle of the variation index is retained, by utilizing the determined intercontinental variation index for a given record or average record position to represent a continental or regional base, as shown in example 25.

EXAMPLE 25.—*Variations for regional and local influences determined by the intercontinental variations*

For record positions in example 17					For record positions in example 19				
		a mean					Wheat harvest		
		Inter.	Regional	Local			Inter.	Regional	Local
pno		*lvx*	*lvx*	*lvx*	*pno*		*lvx*	*lvx*	*lvx*
1		+10.75	−3.25	−6.00	1		+14.75	−2.00	−2.50
2		+11.50	−2.50	−5.25	2		+16.00	−.75	−1.25
3		+12.50	−1.50	−4.25	3		+18.00	+1.25	+.75
4		+16.50	+2.50	−.25	4		+13.50	−3.25	−3.75
5	Berne	+16.75	+2.75	.00	5		+22.00	+5.25	+4.75
6	Geneva	+17.50	+3.50	+.75	6	Berne	+17.25	+.50	.00
7		+11.50	−2.50	−5.25	7	Geneva	+16.75	.00	−.50
8	Average	+14.00	.00	−2.75	8	Average	+16.75	.00	−.50

In example 25 the *inter. lvx* intercontinental latitude variation indices are as determined for the record

positions in examples 17 and 19, while the corresponding *regional* variations are determined by the difference between the *inter. average* and the intercontinental *lvx* for each position, giving results as under regional *lvx*; while the corresponding local variations with Berne or Geneva as the local base are the difference between its intercontinental or regional variation and the corresponding variations for the other positions.

The significant features brought out in this example are in finding the regional variations at different positions to represent the modifying regional influences relative to the intercontinental average *lvx*, and the local variations to represent the modifying local influences relative to Berne or Geneva as the local base position. It will be noted that the range in the regional variations for the positions in example 17 is from *lvx* −3.25 for position 1 to +3.50 for position 6, and for the positions in example 19 from −3.25 for position 4 to +5.25 for position 5, with the range of local variations from the local base for positions in example 17 from −6.00 for position 1 to +0.75 for position 6, and for those of example 19 from −3.75 for position 4 to +4.75 for position 5. Thus position 1 (Santis) of example 17 at 8,200 feet and position 4 (Malaus) of example 19 at 1,800 feet have the lowest minus (warmest) regional and local variations, and position 6 (Geneva) of example 17 at 1,300 feet and position 5 (Lutselfluh) of example 19 at 2,200 feet have the highest plus (coldest) regional and local variations.

These relations show that while there is some difference in the effects of the same continental, regional, and local influences, as represented by the average temperature and the dates of wheat harvest at the local positions, the variations from the requirements of bioclimatic law serve as measurements of the relative intensity and as indices to its interpretation, in that the intercontinental variation serves as an index to the preliminary interpretation of the relative intensity of the continental influences, while the regional and local variations from the average or from the local base serve as a more specific index to the interpretation of the regional and local influences and to the corresponding bioclimatic features to be expected at one position as compared with those to be expected at other record and nonrecord positions.

It is to be kept in mind that the regional and local variations for a given position are to be interpreted and applied separately, one relative to the average influence and the other to the influences prevailing at the local base position, which in example 25 is colder than the average by +2.75, giving −6.00 as the local variation for position 1 from the local base, as compared with −3.25 from the average, thus showing that all variations from both the average and local base are coordinate and relative to the intercontinental requirement constants of the law. It is also to be kept in mind that the zone and zonal types are interpreted by the intercontinental and not by either the regional or local variations.

The significance of this method of finding the regional and local, in addition to the intercontinental, variations for record positions within a given representative region with similar continental influences (e. g., as those of the Swiss, Italian, and Austrian Alps) lies in the fact that preliminary interpretations can be made of the *a* zone and *w* and *c* zonal types for any isophane-altitude position within the given region by simply finding the equivalent position isophane, which plus the *a*, *w*, or *c* *lvx* gives the *iex* isophane equivalent index for each; this (referred to table 3) gives the zone and zonal types represented by the position (as in example 18 for record, or in example 24 for nonrecord, positions). With this preliminary information determined for all representative record and nonrecord positions within the region, the relations of the zones and zonal types to the general and specific topography will serve as a basis for an interpretation of its general (and often specific) bioclimatic features; its relative modifying influences; its seasons; and the adaptations and distribution of its life, agriculture, etc.

These preliminary interpretations may be then confirmed and extended by the regional and local indices as in example 25, and by bioclimatic analyses as described in part 2. Furthermore, all of the preliminary interpretations can be made within a given region from records alone without a single personal observation.

REVIEW OF THE APPLICATION OF INTERCONTINENTAL TABLES OF CONSTANTS

In a discussion of principles, systems, and methods of applying the intercontinental variations to determine regional and local variations, examples 26 to 28*a* will serve to illustrate the methods and comparative results.

EXAMPLE 26.—*Application of intercontinental table 3 to determine zones and zonal types and local variations for positions in example 17*

SECTION A. THERMAL ZONES AND ZONAL TYPES

pno	1	2	3	4	5	6	7	8
a iex	60.25	54.75	55.50	49.25	49.75	48.00	59.00	54.00
a zones	1 −4	11 .2	+.2	.3	.3	−3+4	+.1	.2
w iex	73.00	65.50	63.25	54.00	54.50	53.00	70.25	62.00
w zonal types	1 +.3	1 +.4	1 .4	11 .2	.2	.2	I .3	I .4
c iex	50.00	46.00	50.25	46.00	46.75	44.25	49.75	47.75
c zonal types	11 +.3	.4	+.3	.4	+.4	−.4	.3	+4
climatc types	*caw*	*caw*	*caw*	*caw*	*caw*	*caw*	*caw*	*caw*

SECTION B. LOCAL VARIATIONS AS DETERMINED BY THE INTERCONTINENTAL VARIATIONS

pno	1	2	3	4	5 *lb*	6	7	8
intc. a lvx	+10.75	+11.50	+12.50	+16.50	+16.75	+17.50	+11.50	+14.00
local a lvx	−6.00	−5.25	−4.25	−.25	.00	+.75	−5.25	−2.75
intc. w lvx	+23.50	+22.25	+20.25	+21.25	+21.50	+22.50	+22.75	+22.00
local w lvx	+2.00	+.75	−1.25	−.25	.00	+1.00	+1.25	+.50
intc. c lvx	+.50	+2.75	+7.25	+13.25	+13.75	+13.75	+2.25	+7.75
local c lvx	−13.25	−11.00	−6.50	−.50	.00	.00	−11.50	−6.00

Example 26, section A, shows how the zones, *w* and *c* zonal types, and major climatic types are determined for positions in example 17 by the *iex* to the *ri* referred to appendix table 3.[17]

Section B shows how the local *a*, *w*, and *c* variations relative to the *lb* local base, position 5, Berne, are determined from the intercontinental variations of examples 17 and 18, in which the *intc.* intercontinental *a*, *w*, and *c lvx* for each position minus those of the base position 5 *lb* gives the local *lvx*.

EXAMPLE 27.—*Application of intercontinental table 7 to determine zonal types and local variations for positions in example 19*

SECTION A. HARVEST-DATE ZONAL TYPES

pno	1	2	3	4	5	6	7	8
H iex	47.25	48.75	51.00	46.75	56.00	50.25	47.25	49.50
H zonal types	11+4	−.3	−2+3	+.4	+2	+.3	+4	.3

[17] The *iex* is the same as the *ri* in that it is determined and utilized in the same way for record positions to find the variation, zone, zonal types, etc., hut differs as applied to nonrecord positions, where it serves as an index to the zone, types, and other features represented hy the *ei* of the position as corrected hy the intercontinental or local variation.

EXAMPLE 27.—*Application of intercontinental table 7 to determine zonal types and local variations for positions in example 19*—Con.

SECTION B. LOCAL VARIATIONS AS DETERMINED BY THE INTERCONTINENTAL VARIATIONS

pno	1	2	3	4	5	6	7 *lb*	8 *rb*
intc. H dvx	+59	+64	+72	+54	+88	+69	+67	+67
local H dvx	−8	−3	+5	−13	+21	+2	0	0
intc. H lvx	+14.75	+16.00	+18.00	+13.50	+22.00	+17.25	+16.75	+16.75
local H lvx	−2.00	−.75	+1.25	−3.25	+5.25	+.50	.00	.00

Example 27, section A, shows how the wheat harvest zonal types are determined for positions in example 19 by referring the *iex* to intercontinental table 7.

Section B shows how the local variations for wheat-harvest dates are determined for the same positions by the intercontinental day variations from table 7, in which the local base, position 7, Geneva, and the regional base, position 8, are represented by the same *dvx*. Thus the *intc.* intercontinental *dvx* for each position minus the regional or local base *dvx* +67 gives the regional or local *dvx* for each position; or the *intc. lvx* for each position minus that of the regional or local base gives the regional or local *lvx*, which in each case is equivalent to the local *dvx* divided by 4 (days to 1°).

EXAMPLE 28.—*Interpretation of high altitude limits for wheat culture and altitudes of timber line for positions in examples 17, 19, 20, and 21*

SECTION A. HIGH LIMIT FOR WHEAT CULTURE AS INTERPRETED FROM TABLE 11 AND *avx* IN EXAMPLE 21

pno	Positions in example 17					Positions in example 19				Ex. 21 average
	1	2	3	7	8	4	5	6	8	
pi	29.00	28.75	28.25	27.25	28.25	28.75	28.50	28.25	28.50	29.50
Table 11 *hlc*	8,400	8,500	8,700	9,100	8,700	8,500	8,600	8,700	8,600	8,200
Ex. 21 *avx*	−2,700	−2,700	−2,700	−2,700	−2,700	−2,700	−2,700	−2,700	−2,700	−2,700
Inter. hl	5,700	5,800	6,000	6,400	6,000	5,800	5,900	6,000	5,900	5,500

SECTION B. ALTITUDE OF TIMBER LINE AS INTERPRETED FROM TABLE 10 AND *avx* IN EXAMPLE 20

pno	Positions in example 17					Positions in example 19				Ex. 20 average
	1	2	3	7	8	4	5	6	8	
pi	29.00	28.75	28.25	27.25	28.25	28.75	28.50	28.25	28.50	28.50
Table 10 *tlc*	11,200	11,300	11,500	11,900	11,500	11,300	11,400	11,500	11,400	11,400
Ex. 20 *avx*	−5,100	−5,100	−5,100	−5,100	−5,100	−5,100	−5,100	−5,100	−5,100	−5,100
Inter. tl	6,100	6,200	6,400	6,800	6,400	6,200	6,300	6,400	6,300	6,300

Example 28, section A, shows how the high altitude limits for winter wheat culture are interpreted from intercontinental table 11 relative to altitudes below or above selected high positions in examples 17 and 19; the *hlc* high limit intercontinental constant is determined by referring the *pi* for each position to table 11, which minus the determined average *avx* of example 21 gives the *inter.* interpreted *hl* high limit for each position relative to the average.

In section B the altitude for timber line relative to the same positions is interpreted from table 10 in the same way as in section A.

EXAMPLE 28*a*.—*Variations relative to different base positions*

	Intc.	*8 cont.*	5 Berne	6 Geneva	1 Santis
Intc	0.00	+14.00	+16.75	+17.50	+10.75
8	−14.00	.00	+2.75	+3.50	−3.25
5	−16.75	−2.75	.00	+.75	−6.00
6	−17.50	−3.50	−.75	.00	−6.75
1	−10.75	+3.25	+6.00	+6.75	.00

COORDINATION OF INTERCONTINENTAL, CONTINENTAL, REGIONAL, AND LOCAL BASE POSITIONS

Studies of the principle of the coordination of intercontinental, continental, and local variations have shown that by means of the intercontinental variation any selected average or specific position can be converted into a continental, regional, or local base simply by utilizing its intercontinental variation for comparison with that of any other record position of the same continent, region, or local area as in example 28*a*, in which the first line gives the abbreviations for the *intc.*, *8 cont.* as the average position, and for 5 Berne, 6 Geneva, and 1 Santis of example 17 as local base positions. Under each of these positions are given on the *intc.* line the intercontinental *lev* variations and on lines 8 to 1, the continental for position 8 and the local variations for positions 5, 6 and 1.

Thus with 0.00 no variation for the intercontinental base, the intercontinental variations are +14.00 for position 8, +16.75 for position 5, +17.50 for position 6, and +10.75 for position 1, with the plus signs reversed for each position under *intc.* to represent the corresponding variation at the intercontinental base as computed from the continental and each of the local base positions, then the difference between the intercontinental variation of one base and that of another gives the continental and local variations for each as would be computed from each zero base.

The application of this principle of coordinate variations from different base positions as shown in this example is simply to find the difference between the intercontinental variation of one and that of any given continental or local base. Then the variation from the continental or local base for any number of positions will be the same as if a table of constants were computed from the records of each base position.

In further reference to the principle and significance of the bioclimatic base, it is to be kept in mind that, due to the complete coordination of the rates in units of time, temperature, and distance from which the tables of constants are computed, there is under this standard system a complete coordination of intercontinental, continental, regional, and local base positions, in which the difference between the constants

computed from one base and those computed from another is always represented by the determined variation of the position record from its intercontinental constant.

Example 28b.—*Interpreted high-altitude limits of winter wheat culture and altitudes of timber line for positions in examples 17 and 19 as modified by local w and H variations*

INTERPRETED HIGH LIMITS FOR WINTER WHEAT

pno	Positions in example 17					Positions in example 19				Ex. 21 average
	1	2	3	7	8	4	5	6	8	
Ex. 28 *inter. hl*	5,700	5,800	6,000	6,400	6,000	5,800	5,900	6,000	5,900	5,500
w and *H local avx*	−800	−300	+500	−500	−200	+1,300	−2,100	−200	0	-----
Modified *hl*	4,900	5,500	6,500	5,900	5,800	7,100	3,800	5,800	5,900	5,500

INTERPRETED ALTITUDE OF TIMBER LINE

pno	Positions in example 17					Positions in example 19				Ex. 20 average
	1	2	3	7	8	4	5	6	8	
Ex. 28 *inter. tl*	6,100	6,200	6,400	6,800	6,400	6,200	6,300	6,400	6,300	6,300
w and *H local avx*	−800	−300	+500	−500	−200	+1,300	−2,100	−200	0	-----
Modified *tl*	5,300	5,900	6,900	6,300	6,200	7,500	4,200	6,200	6,300	6,300

INDICES TO MODIFIED ALTITUDE LIMITS

It is evident that the altitude limits of wheat culture as well as that of trees is controlled largely by the prevailing type of regional and local climate, with the principal index for wheat limit to be found in the variation of the mean of the warmest month and of the date of wheat harvest within a given region, because the *w* mean and *H* wheat harvest *local* variations for given positions serve as reliable indices to modified altitude limits within the represented area. We may thus expect the interpreted *hl* and *tl* altitudes in example 28 to be as in example 28b, in which it will be noted by utilizing the *w* and *H* local variations to correct the interpreted *hl* and *tl*, the minus *avx* (*w lvx* of example 26 sec. B or *H lvx* of example 27 sec. B multiplied by 400 feet) gives a lower, and the plus a higher, interpreted altitude; these all evidently fit the facts except at positions 4 and 5 of example 19, in which that for position 4 is apparently too high and that for position 5 too low. In this example the *w* local *avx* applies to positions in example 17, while the *H* local *avx* applies to positions in example 19.

Further studies of the relations of the local *w* and *H* variations to the interpretation of local high limits of wheat culture and timber line will determine whether or not they are reliable enough for preliminary information on these subjects.

The altitude difference between the limits of wheat culture and of timber line in the Swiss Alps come within a range of 400 feet, while the difference between the requirement constants of tables 11 and 10 is 2,800 feet. The apparent reason for this difference is in the major and minor climatic types through the relative *w*, *a*, and *c* warm and cold variations, in which the cool *w* type contributes to a low timber line and the warm *c* type to a higher limit for wheat culture.

APPLICATION OF WHEAT HARVEST RECORD DATES IN WESTERN EUROPE

As a further test of finding the intercontinental and continental variations, 22 record positions with average wheat harvest dates were selected from a long list to represent the general wheat growing region of western Europe, ranging from Switzerland north to Norway and Finland, and from east longitude 6 to 27, with a range in altitude from sea level in Norway and Finland to 3,000 feet in Austria.

Example 29.—*List of selected record positions for wheat harvest dates in Europe*

pno	Position	Country	*pi*	*plo*	*pa*	*ei*	No. yrs.	Intc. table 7			Local	*zt*
								pc	*pr*	*dvx*	*dvx*	
1	Bodo	Norway	50.00	14	0	50.00	3	196	252	+56	−11	1 .4
2	Uleahorg	Finland	50.00	25	0	50.00	19	196	231	+35	−32	II .1
3	Kuopio	do	48.25	27	100	48.50	9	190	219	+29	−38	+.2
4	Helsingfors	do	45.00	25	100	45.25	3	177	187	+10	−57	+4
5	Baltischport	Estonia	44.00	24	0	44.00	1	172	223	+51	−16	+2
6	Pernau	do	43.25	24	100	43.50	?	170	211	+41	−26	.2
7	Riga	Latvia	41.75	24	0	41.75	6	163	210	+47	−20	.2
8	Arys	Germany	38.00	21	500	39.25	14	153	211	+58	−9	.2
9	Kurwien	do	37.75?	21?	400	38.75	6	151	207	+56	−11	−.2
10	Eutin	do	36.25	10	100	36.50	8	142	207	+65	−2	−.2
11	Berlin	do	35.00	13	100	35.25	11	137	194	+57	−10	.3
12	Pilzno	Poland	34.25	21	800	36.25	3	141	198	+57	−10	+3
13	Friedrichroda	Germany	33.50	10	1,200	36.50	7	142	224	+82	+15	−1+2
14	Leutschau	Czechoslovakia	33.00	20	1,800	37.50	9	146	209	+63	−4	.2
15	Giessen	Germany	32.25	8	500	33.50	?	130	199	+69	+2	+3
16	Nagy Michaly	Czechoslovakia	33.00	21	400	34.00	21	132	185	+53	−14	+4
17	Darmstadt	Germany	31.50	8	500	32.75	3	127	194	+67	0	.3
18	Bleiberg	Austria	29.25	13	3,000	36.75	3	143	215	+72	+5	.2
19	Hausdorf	do	29.50?	14?	3,000	37.00	2	144	203	+59	−8	−2
20	Zurich	Switzerland	29.00	8	1,600	33.00	35	128	200	+72	+5	−2+3
21	Berne	do	28.25	7	1,900	33.00	3	128	197	+69	+2	+.3
22	Geneva	do	27.25	6	1,300	30.50	3	118	185	+67	0	+4

Authority for records: Phaenologische Beobachtungen vom Winterroggen; Inaugural Dissertation bei der Philosophischen Facultät Zu Giessen, by Philipp Made, 1890.

Example 29 gives the usual geographic coordinates for the 22 positions with *no. yrs* number of record years on which averages of records are based; *pc* the year-date position constant from table 7; *pr* the average position year-date record; *intc. dvx* the intercontinental day variation index; *local dvx* the day variation index; and *zt* the wheat harvest zonal type for each position as determined from table 7.

In this example either position 22, Geneva, or 17, Darmstadt, serves as the local or continental base, because they both have the same intercontinental *dvx* of +67 days. Therefore, the difference between the base variation index and that of any other position gives the local variation for it, as a measure of the intensity of the continental and local influences relative to that prevailing at Geneva or Darmstadt instead of to that prevailing at the intercontinental base.

The object of this example is to show how to apply the continental variations for any position in western Europe, and thus make them available for interpreting

average harvest dates for local nonrecord positions in the areas or regions represented by the nearest record position. In such applications to nonrecord positions, however, it is to be expected that there will be a further variation from the constants for altitude positions below and above that of the representative local record positions in that, as a rule, the lower valley positions will be relatively colder with later dates than their requirement constants for the position altitudes, and the higher slope and summit positions will be relatively warmer with earlier dates.

The outstanding and significant features of the local variations in this example are (1) the general minus warmer variations and earlier dates for positions above 13, with a maximum of 57 days earlier at position 4 in Finland and a minimum of 2 days earlier at position 10 in Germany; (2) the extreme plus colder variation of 15 days later at position 13 in Germany; and (3) the normal (0) for positions 17, Darmstadt and 22, Geneva. This shows, in general, that north of about isophane 33.00 and east of about meridians 13 or 14 the wheat harvest dates are earlier than the continental requirement, while south of about the same isophane and west of the same meridians the dates are either later or earlier.

The plus intercontinental variations indicate that the growing season of western Europe as a whole has a cool retarding influence on the ripening of wheat, comparable to that of the western coast region of North America. This feature in itself furnishes a significant basis for comparative interpretations relative to regions on different continents with the same or very different types of climate.

A comparative study of the wheat harvest zonal types brings out some striking and significant features in that (1) with the exception of positions 4, 11, 16, 17, 21, and 22, the zonal types are above the requirement high limit zonal constant (major II minor +.3) for winter wheat culture; (2) position 1 shows an extreme zonal type equivalent to the normal for the Arctic Circle; (3) for positions 4, 16, and 22 the type is in the optimum zone (minor 4) for winter wheat culture; and (4) for position 21 at 1,900 feet the zonal type is equivalent to the high limit zone.

This indicates the relative intensity of the prevailing continental and regional influences which govern and modify the growing season and altitude limits for winter wheat culture in central and western Europe; the relative warm winters modify the effects of the cool summers. It is to be kept in mind that the zonal types in this example are determined by the harvest records and, therefore, do not indicate the high limit zone of wheat culture. Thus, while the harvest type for Berne at 1,900 feet is the same as the limit zone +.3, the modified limit (example 28*b*) is at 5,800 feet, or 3,900 feet above the position altitude, due to the modifying influence of the relatively warm winter.

CONCLUSIONS

Many further studies were made of the culture zones in the Alps, but the most significant result of the application of bioclimatic principles for the interpretation of the bioclimatic elements in this region was the determination of the facts that (*a*) from a region of which a great deal is known, preliminary interpretations can be made for regions of which little is known, without the need of an expensive survey and years of study; (*b*) thermal, time, and distance records from a few representative record positions are sufficient to interpret the general bioclimatic features of a well-known region, without utilizing the mass of published information about it; and (*c*) the same principles and methods are applicable to any little-known region, for which only a few representative records are available.

Thus the most important features brought out in the preceding examples and discussion are in the demonstration that (1) with thermal, time, and distance (altitude) records for a few representative positions in any area or region, reasonably accurate interpretations can be made as to its general bioclimatic character and agricultural development for which it is best adapted; (2) with thermal, time, and distance data from a large number of representative positions, a preliminary analysis of the bioclimatic and zonal elements can be made to a point where local studies can complete the analysis; and (3) the requirements for success are the readjustment and development of local possibilities in agriculture or related industries through practical experience and experiments, guided by local biologic and ecologic features and by phenological records of seasonal events.

APPLICATIONS IN PHENOLOGY, ENTOMOLOGY, AND AGRICULTURE

This section contains concrete examples of applied bioclimatics with special reference to (1) flowering dates of plants, (2) wheat seeding dates and the hessian fly, (3) general entomological research and practice, and (4) agricultural practices.

IN PHENOLOGY

The following discussion of the application of bioclimatics in phenology is based on records of the flowering dates of a large number of plants throughout the British Isles and Germany during a long period of years as summarized and published in special reports by Clark and Adames [18] for the British Isles and by Ihne [19] for Germany. These contributions are outstanding classics in the science of phenology and are of special value to bioclimatics, in that they make available an ideal set of data for testing the reliability of the bioclimatic method.

In 1921 the writer made a comprehensive study of the recorded dates in the British Isles and Germany of the flowering of the hawthorn (*Crataegus oxyacantha*) for 1915 to 1918. In addition, studies were made of the 25-year average of the flowering dates of 13 plants in the British Isles, as summarized by Clark and Adames.[20]

The intercontinental constants were computed from the Kanawha Farms base for comparison with the record dates for the hawthorn event at Tenbury, England, and Darmstadt, Germany; while the local constants were computed from these two local base positions. At that time the only available record date of the flowering of the English hawthorn for the intercontinental base was that for 1920 at Parkersburg, W. Va., this date was found to agree closely that year with the date of the unfolding of *Hicoria* leaves; and at Kanawha Farms records of this latter event were available for 1915 to 1918. The average of these dates

[18] CLARK, J. E., and ADAMES, H. B., ANNUAL REPORTS ON THE PHENOLOGICAL OBSERVATIONS IN THE BRITISH ISLES. Quart. Jour. Roy. Met. Soc. 1916–21.

[19] IHNE, E., PHAENOLOGISCHE MITTEILUNGEN. Arb. Landw. f. Hessen, Jahrg. 1907, 1908, and Hefts 6, 8, 11, 13, 16, 17, 20, 21, 23, 24. 1908–19.

[20] The principal results of these studies were given in the following publication: HOPKINS, A. D., INTERCONTINENTAL PROBLEMS IN BIOCLIMATICS WITH SPECIAL REFERENCE TO NATURAL AND ARTIFICIAL DISTRIBUTION OF PLANTS AND ANIMALS. Jour. Wash. Acad. Sci. 11: 223–227.

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for the base equivalent isophane 44.50 was May 9, year-date 129, and for the sea-level base isophane 43, May 3, year-date 123, which was utilized as the base date, from which the intercontinental constants were computed for the eastern sea-level isophanes.[21]

Example 30.—*Comparison of ranges in local and intercontinental variations of average record dates of the flowering of hawthorn and of 13 plants in the British Isles by local positions and districts*

SECTION A. RANGES IN VARIATIONS OF 4-YEAR AVERAGE DATES OF THE HAWTHORN EVENT FOR LOCAL POSITIONS

Tenbury base position, lat. 52.25°, long. 2W, alt. 300 feet, isop. 31.75, average record date May 14, year-date 134.
Range in record positions, isop. 29.25 to 37.75, long. 1E to 9W, alt. 0 to 800 feet.

Number of years records, 1915–18	4	
Number of record positions, omitting base	86	
Number of positions with (−) earlier variations	41	*Days*
Range in earlier variations		0 to −10
Number of positions 8 days or more earlier	5	
Average of earlier variations		−3.68
Number of positions with (+) later variations	43	
Range in later variations		0 to +12
Number of positions 8 days or more later	5	
Average of later variations		+3.69
Number of positions with no variations	2	
Intercontinental variations:		
Intercontinental variation for tbe base position		+60
Range in (+) later variations, 87 positions		+50 to +72
Number of positions with +70 days or more variation	2	
General average variation		+60.6
General average local variation		+0.6

SECTION B. RANGES IN VARIATIONS OF 25-YEAR AVERAGE DATES OF THE HAWTHORN EVENT BY DISTRICTS

District D base average position, lat. 53, long. 2W, alt. 200 feet, isop. 32.50, average date May 14, year-date 134.
Range in average positions of districts, isop. 30.25 to 36.50, alt. 200 to 300 feet.

Number of years records, 1891–1915	25	
Number of record districts, omitting base	10	
Number of districts witb (−) earlier variations	3	*Days*
Range in earlier variations		−2 to −5
Average of earlier variations		−3.33
Number of districts witb (+) later variations	5	
Range in later variations		+1 to +5
Average of later variations		+3.40
Intercontinental variations:		
Intercontinental variation for tbe base position		+60
Range in (+) later variations, 11 districts		+55 to +65
General average variation, 11 districts		+60.6
General average local variation		+0.6

SECTION C. RANGES IN VARIATIONS OF 25-YEAR AVERAGE FLOWERING DATES OF THIRTEEN PLANTS BY DISTRICTS

Base average position same as in section B.

Number of years records, 1891–1915	25	
Number of record districts, omitting base	10	
Number of districts with (−) earlier variations	4	*Days*
Range in earlier variations		−1 to −11
Average of earlier variations		−6.50
Number of districts with (+) later variations	6	
Range in later variations		+1 to +5
Average of later variations		+2.83
Intercontinental variations:		
Intercontinental variation for tbe base position		+60
Range in (+) later variations, 11 districts		+49 to +65
General average variation, 11 districts		+59.1
General average local variation		−0.9

The data given in example 30, section A, are from local constants computed for each of the 86 positions from the average date at Tenbury as the local base, and the intercontinental variations are from intercontinental constants computed for the positions including Tenbury from records at the intercontinental base, and that the given ranges in minus earlier and plus later variations, and thus in corresponding dates, by the given number of days include all local positions relative to the local base, and all positions including the local base relative to the intercontinental base, with the general average +60.6 days and the local +0.6 of a day. This indicates that without the local records the 4-year average dates for all of the record positions could have been predicted within a reasonable range of error from the records at the intercontinental base. It is also plainly evident that from the average variations for each district, the average date could be predicted for any number of positions within the British Isles.

In section B the ranges in local variations for the record hawthorn event are from local constants computed from the 25-year average records for positions in district D to serve as the local region base for the other 10 districts, while the intercontinental variation is given for this base and the range for the 11 districts. It will be noted that the general average intercontinental variation is +60.6 days giving the average local variation as +0.6 of a day.

In section C the variations from the constants for the average record dates of the flowering event of 13 species of plants are determined for the same ten districts as in section B, with the intercontinental variations determined in the same way. It will be noted that the general average of the intercontinental variations is +59.1 days giving a local average of −0.9 of a day.

Example 31.—*Comparison of ranges in local and intercontinental variations of average record dates of the flowering of hawthorn in Germany by local positions*

SECTION A. RANGES IN VARIATIONS OF 4-YEAR AVERAGE DATES

Darmstadt base position, lat. 49.75°, long. 8E, alt. 400 feet, isop. 31.50, average record date May 9, year-date 129.
Range in record positions, isop. 29.50 to 36.25, long. 7E to 16E, alt. 100 to 2100 feet.

Number of years records, 1915–18	4	
Number of record positions, omitting base	21	
Number of positions with (−) earlier variations	11	*Days*
Range in earlier variations [1]		−1 to −18.5
Average of earlier variations, 11 positions		−6.35
Number of positions 7 days or more earlier	4	
Number of positions with (+) later variations	10	
Range in later variations, 10 positions		+1 to +6.7
Number of positions with 6 days or more later	1	
Average of later variations, 10 positions		+2.55
Intercontinental variations:		
Intercontinental variation for tbe base position		+55
Range in (+) later variations, 22 positions		+36 to +62
General average variation, 22 positions		+52.9
General average local variation		−2.1

SECTION B. RANGES IN VARIATIONS OF 12-YEAR AVERAGE DATES

Record positions, same as in tbe preceding.
Base position, same as in the preceding.

Number of positions with (−) earlier variations	10	*Days*
Range in earlier variations		−0.09 to −7.99
Number of positions 7 days or more earlier	2	
Number of positions less than 1 day earlier	4	
Average of earlier variations, 10 positions		−3.36
Number of positions with (+) later variations	11	
Range in later variations		+0.41 to +9
Number of positions 7 days or more later	1	
Number of positions less than 1 day later	1	
Average of later variations, 11 positions		+3.64
Intercontinental variations:		
Intercontinental variation for the base position		+55
Range in (+) later variations, 22 positions		+47 to +64
General average variation, 22 positions		+55.1
General average local variation		+0.1

1. The local variation for one position (Reinerz) is −18.5 days because of a variation of −26 days for 1917, while the 12-year average for tbe same position gives a variation of only −3.88 days, tbus indicating an error for 1917, which would reduce the average for the 4-year records.

In example 31, section A, the local variations of the record hawthorn event for 4 years at 21 positions in Germany are relative to Darmstadt as the local base; and the intercontinental variations for the 22 positions are relative to the intercontinental base, with the general average intercontinental variation +52.9 days, and the general average local variation −2.1 days.

In section B the period is for 12 years for the same event and the same positions relative to the same base, with the general average intercontinental variation +55.1 days, and the general average local variation +0.1 day. This example shows, as in the preceding, that the average dates of the hawthorn event could have been predicted from the intercontinental or local base for all of the positions within an allowable range of error, and in a few cases with perhaps a less range than that of the record average.

[21] Tbe average date of tbe flowering of tbe Englisb bawthorn at Kanawba Farms up to the spring of 1930 is May 2, *yd* 122, from wbicb tbe revised intercontinental constants were computed, for comparison with the position records of tbe British Isles and Germany.

EXAMPLE 32.—*Comparison of grand averages of local and intercontinental variations*

	Var. in days	
	Intc.	*Local*
Example 30. British Isles:		
Sec. A. Hawthorn, 4 years:		
Variation for Tenbury base	+60	0
Range 87 positions, +50 to +72	+50	−10
	+72	+12
General average 87 positions	+60.6	+0.6
Sec. B. Hawthorn, 25 years:		
Variation for district D base	+60	0
Range 11 districts, +55 to +65	+55	−5
	+65	+5
General average 11 districts	+60.6	+0.6
Sec. C. Thirteen species of plant, 25 years:		
Variation for district D base	+60	0
Range 11 districts, +49 to +65	+49	−11
	+65	+5
General average 11 districts	+59.1	−0.9
Example 31. Germany:		
Sec. A. Hawthorn, 4 years:		
Variation for Darmstadt base	+55	0
Range 22 positions, +36 to +62	+36	−19
	+62	+7
General average 22 positions	+52.9	−2.1
Sec. B. Hawthorn, 12 years:		
Variation for Darmstadt base	+55	0
Range 22 positions, +47 to +64	+47	−8
	+64	+9
General average 22 positions	+55.1	+0.1

IN ENTOMOLOGY

In the development of applied bioclimatics the application in economic entomology includes comprehensive studies of a number of the principal insect enemies of forest trees, vegetables, fruits, and farm crops. The more important results and conclusions of these studies are here summarized, the details being reserved for subsequent publication. Among these outstanding and significant results are:

1. The demonstrated simplicity, efficiency, and economy of time and money in securing desired information on (*a*) the natural and artificial geographic distribution of native and introduced insects; (*b*) the climatic and seasonal conditions to which they are best adapted, as indicated by the zonal and zonal type centers of abundance; (*c*) the zonal and zonal type indices to the number of seasonal or annual generations of a species to be expected at a specific position within the limits of its latitude and altitude; and (*d*) indices to the critical or optimum time at given positions to apply preventive and remedial measures.
2. The demonstrated possibility and practicability of securing by the bioclimatic method more information about the native distribution and zonal adaptation of an introduced insect than is usually obtained by special explorations.
3. Prediction of the probable distribution and relative importance of an introduced insect from its known zonal and zonal type distribution in the continent or region from which it was introduced.

THE MEXICAN BEAN BEETLE

Bioclimatic studies of the Mexican bean beetle in 1922 indicated that its very restricted distribution would extend to the limits of its food plants, which it did.

Further studies in 1924 to 1927 served to verify the first prediction and led to the further conclusions that in an average season the number of generations of this beetle that may occur within its range is four in major zone II minor 7; three, from lower 6 to middle 5; two, from middle 5 to upper 4; and one, from upper 4 to minor 2.

THE CODLING MOTH

Studies of the codling moth in 1920 indicated that if the predictions, as to time of seasonal events and number of generations at the places from which recorded data are available, come close to the actual records, it will be safe to assume that they will hold as a general average index for any other place within the latitude and altitude distribution of the insect, and that, where there is a decided variation from the constant at record positions, this variation can be utilized as an index for the correction of date constants for nonrecord positions within the general area and thus provide a method of prediction that is more reliable than any other method of interpretation heretofore devised.

Subsequent studies in 1929 served to verify the first conclusions and to indicate further that (1) the record minor zone represented by a geographic position or local area is a reliable index to the number of generations to be expected in a normal season; (2) the number of annual generations of larvae leaving fruit for different minor zones is as follows:

One generation	Major II minor 2.
Two generations	Minor 3.
Three generations	Minor 4.
Four generations	Minor 5.
Five generations—possibly larvae of the fifth generation in the extreme southern limit of apple culture in	Minor 6.

(3) as a rule for most positions, the record *a* zone is sufficient to indicate the number of generations, but in the extreme western-coast climatic type with very cool summers, the (*w*) warmest month index will give the *w* type of the *a* zone and thus indicate the number of generations to be expected; (4) the minor zone, zonal section, or zonal type is the best index to an interpretation of the geographical distribution of this insect and to the number of generations and seasonal behavior to be expected at any given position within its distribution; (5) the variations of the *a*, *w*, and *c* position records from the requirement thermal and zonal constants of appendix table 3 represent a true measure of the relative intensity of modifying influences, and thus serve as the most reliable indices to certain bioclimatic features and seasonal behavior of plants and animals in general: (6) for given seasons allowance must be made for seasonal variations from the normal or average interpreted date, as controlled by local weather conditions, in which early and late seasons are best indicated by the development of the flower and leaf buds of the apple and subsequent development of the foliage and fruit, supplemented by corresponding events of other plants of the immediate locality up to the end of the season; and (7) it is to be assumed that the science of bioclimatics is equally applicable to other insects and similar problems involving (*a*) a consideration of the interpretation of seasonal history events, and bioclimatic elements; (*b*) the range and limits of the distribution of a species; (*c*) the number of generations to be expected within a given minor zone or zonal type; (*d*) their relations to the minor zone and zonal types of a given region, local area, or specific place; and (*e*) application in the practical control of the species.

THE GYPSY MOTH

Bioclimatic studies of the gypsy moth made in 1921, with reference to the problem of introducing parasites

from Japan, indicated that (1) in order to attain the best success the parasites should be sought in the same eastern coast type of zone in Japan as that in which the moth prevails in New England; and (2) by means of the thermal principle and method, the zonal types may be quickly determined for the whole of Japan and shown by maps and charts to guide the explorer in his search for the parasites.

THE EUROPEAN CORN BORER

In 1928 and 1929 a comprehensive study was made of the European corn borer with special reference to its zonal and zonal type distribution both in Eurasia and in this country. The results indicated that (1) the one- and two-generation types of the insect had come from the same zone or type somewhere in Eurasia as that in which it has survived and spread in this country; and (2) therefore, in accordance with a conceived *zonal selection principle* [22] its southern and southwestern distribution into the warmer corn belt zone was not to be expected.

Further studies of the zone, zonal type, centers of distribution, and zonal selection principle indicated that:

1. The *a* zone for one generation comes between lower minor zone 2 and upper 4 in Europe, and between lower middle 3 and upper middle 4 in America; and for two generations it comes in lower 4 to upper 6 in Europe, and in upper middle 4 to upper 4 in New England.
2. The *w* type for one generation is middle 2 to upper 4 in Europe, and upper middle 4 to middle 4 in New York and Ohio; and for two generations from middle 4 to lower middle 4 in Europe, and middle 3 to upper middle 4 in New England.
3. The optimum zone for the insect is *a* zone 4, which is the optimum zone for corn production, with the center of production in Europe and America in about middle minor zone 4.
4. Both the one and two generations predominate in minor zone 4, but the centers for one generation by zones and types come in minor 2 to upper 4, while the centers for two generations come in minors 4 to 6.
5. In general the *w* types are higher and colder and the *c* types lower and warmer than the *a* zone, which is more evident in the European centers than in the American, thus indicating that summer heat is the controlling influence, restricting the distribution in North America to the region above the optimum center of corn production.
6. Special precaution should be taken to prevent the introduction from Europe of the insect from the optimum middle and lower zone 4, where two generations prevail, into middle zone 4, the optimum for corn production in the United States.

THE MEDITERRANEAN FRUITFLY

In 1930 special studies were made of the Mediterranean fruitfly with reference to its zonal distribution and adaptation in the Eastern Hemisphere with special reference to the danger of its establishment in Florida. The results indicated that the zonal type conditions as represented by heat and rainfall of the summer months in Florida were unfavorable for the insect to survive there.

THE PERIODICAL CICADA

Special studies of the 1897, 1914, and 1931 broods of the periodical cicada (as shown in publications by the writer) indicated that the average rate of variation in the time of emergence for 400 feet of altitude was about 1.4 days, and for 1° of latitude about 3 days. It is evident, therefore, that altitude affects the periodical emergence of the cicada less than latitude and that both these factors here have less than the normal influence (4 days for 1° and 400 feet) that they have on plants and insects which develop above the ground and are exposed to the free circulation of the air. This would indicate that this soil-inhabiting insect tends to vary with variation in latitude and altitude in the same way as do air-inhabiting species, but at a lesser rate, in response to the controlling influences represented by the bioclimatic law.

This lower rate is probably accounted for by the fact that the soil maintains a more even temperature through the seasons of activity and rest, and at the same time the cicada is affected much less by the variable weather conditions of early and late spring and other seasons than are organisms which live above ground. Then again, during this long period of development of the cicada the accelerating influences of one season are balanced by the retarding influences of another, so that the ultimate response in the subterranean development up to the time of emergence from the ground is not to the specific influences of the particular season of emergence but to the average of the 17 seasons of development.

IN RELATION TO WINTER WHEAT AND THE HESSIAN FLY

The results of a comprehensive study of some 40,000 records of winter wheat seeding and harvest dates within the range of winter wheat culture in the United States of America (Monthly Weather Review supp. 9, 1918) furnish an outstanding example of the application of bioclimatic principles to the investigation of a national agricultural problem.

PURPOSE OF THE INVESTIGATION

The progress of the World War in Europe, and the consequent possibilities of this country being drawn into the struggle, made it apparent to President Wilson and his Cabinet that there would be urgent need of a material increase in food supplies. This led to the direction of the energies of the Department of Agriculture toward the attainment of the desired objective through research by experts in its various bureaus.

Realizing the importance of wheat as a source of food, the serious reduction in the crop often caused by the hessian fly, and that one of the principal recognized methods of avoiding the damage was the seeding of wheat after the average date of the ending of the flight of the fly, the writer requested that he be allowed to use bioclimatic principles and methods to help solve the problem of selecting the proper seeding time for different local areas and regions within the latitude, longitude, and altitude range of wheat culture. This request was granted by the Chief of the Bureau, L. O. Howard, and resulted in the publication cited.

RESULTS

One of the first important results of a study of the literature on the best time for seeding wheat in given localities, and on the normal time for the ending of the flight and deposition of the eggs of the fly, was the finding that ***the best time to seed for the best crop in a given locality was also the best time to seed to avoid damage by the fly.*** Other important results to mention in this connection were in finding that:

[22] This principle assumes that a given species may become so selected to a minor bioclimatic zone or its type that it will not survive in any other to which it may be introduced.

1. Under equal climatic and other influences, the best time to seed wheat in certain representative localities and the time of the normal ending of the flight and oviposition of the fly at the same position agreed closely with the requirements of the bioclimatic law.

2. With differences in latitude, longitude, and altitude, and at the same time marked differences in bioclimatic features relative to the base station and local base area of Wooster, Ohio, there were corresponding earlier or later variations of the recorded dates from the requirement date constants of the law.

3. The determined average variations of earlier and later records for counties, states, and geographic quadrants served to indicate clearly the relative intensity of the local and regional warmer influences, as represented by earlier harvest in the summer and later seeding dates in autumn, and of colder influences, as represented by the later harvest dates in summer and earlier seeding dates in autumn.

within the range of the area represented by a given variation.

7. The average period between seeding and harvest varied with geographic positions, and its variation from the requirement constants of the law served as an index to the regional and local influences of the year, the latitude and altitude range and limits, and the optimum zones of wheat culture.

8. Wheat-seeding calendars of dates, together with charts of coordinate isophanes at, and altitudes above, sea level could be prepared for any county or State, or for the whole country, which (with simple instructions) would enable the wheat grower to utilize the given local or regional variation index to determine for himself the proper average date or time for seeding wheat in his immediate locality and on his farm.

9. The averages of the variations of the record dates from the requirement date constants of the law for local areas, or for the entire country, could be shown on outline maps and thus made available for application

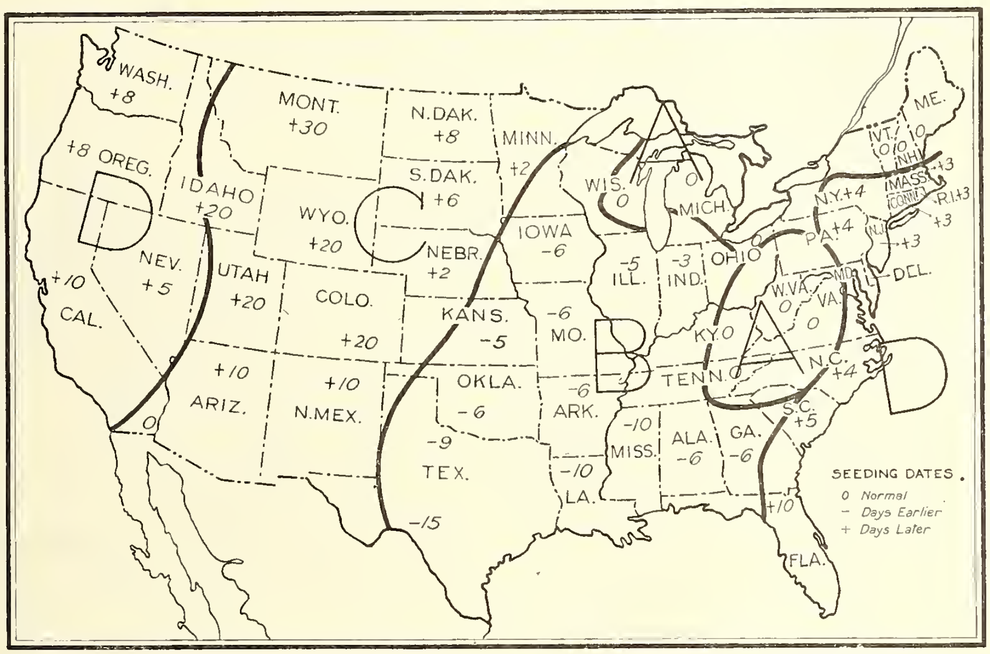

FIGURE 26.—Map of the United States with average variations for winter-wheat seeding dates by States and regions.

4. By utilizing the earlier or later variations of the average of the record dates from the requirement constants for given geographic positions (as *indices* to the variations to be expected within local and general areas), *it was possible*, by bioclimatic principles and methods, *to interpret or predict the average "fly-free dates" and best date for seeding wheat at any position within the area or region represented by the given variation indices.*

5. *Such interpretations* by means of map calendars of dates for specific isophane and altitude positions (as prepared in July 1917, for New York, West Virginia, North Carolina, and other States) *agreed so closely* (as reported and checked by experiment station officials) *with the best practice as to be recognized as a striking verification of the law and of the principles and methods involved.*

6. The same principles and methods applied to the average records of wheat-harvest dates gave variations for counties, States, and geographic quadrants, by which the average harvest time could be predicted for any geographic position of known isophane and altitude

to the map-calendar charts to find the average dates for seeding and harvest, and the length of the period in days for any given local area within the range of wheat culture, as in figures 26 and 27.

Figures 26 and 27 give the general average variations or departures in (+) days later and (−) days earlier than the requirement constants for the States and regions, as determined from the average departures (in days) of record dates from their requirement constants for each county.

These maps show, in addition to variations, the major regional influences in causing earlier and later seeding and harvest dates; (+) seeding signifies that the autumn is warmer and the seeding date later, and (−) that it is colder and the seeding date earlier than the requirement constant, while a (+) harvest signifies that the summer is colder with later harvest and a (−) indicates warmer and earlier. These warmer and colder effects of the regional influences apply alike to the average altitudes within the State, but will vary somewhat with higher and lower altitudes.

Evidence of Major Regions

In a general study and interpretation of the average departures for 5° by 5° quadrants, counties, and States, the fact was revealed that there are four distinctive major regions, designated on the maps as A, B, C, and D, each with more or less radically different influences as affecting the seeding and harvest dates, periods between dates, latitude and altitude limits of winter wheat culture, and seasonal activities of the hessian fly. (These are explained and discussed on pp. 19 and 20 of the original publication.)

RESULTS OF FURTHER STUDIES

With the results of further studies and test examples, the following revised explanations may give a clearer conception of the practical importance of some of the principles and methods.

The General Average Variation

It is to be kept in mind that the broad general average variations often represent many hundreds of records for a 5° by 5° quadrant or county and many thousands for some of the States, and that these variations serve especially to reflect the trend and relative intensity of the major retarding or accelerating influences on the seasonal events of the wheat plant and its insect enemy; also that, while the general average departure for a State indicates the days later or days earlier than the requirements of bioclimatic law, it does not indicate the often wide local range in late or early departures within a quadrant, county, district, or locality due to local influences. Thus the State departures, while available for indicating major regional influences, are not available for indicating local influences or for the interpretation of dates for local areas or places in different seasons without corrections for such local or season influences.

It will be noted that there are slight differences in the indicated A and D regions as represented by variations for seeding and harvest, but these differences are to be expected as the harvest event, seeding event, and seeding to harvest period represent different types of effect of the same regional influences at different times and during different periods of the year.

The outstanding and significant features of the State variation indices as shown on the maps are (1) in demonstrating the existence of distinctive major regions of prevailing normal, retarding, and accelerating influences as affecting the wheat plant and its insect enemy; and (2) in indicating that, as shown in preceding and following examples *similar effects on other crop plants, crop pests, and on general economic practice in agriculture do prevail within these regions.*

Local Variations for Counties and 1° by 1° Quadrants

Results of the original and subsequent studies of the winter wheat record data and of the range in the departures of the record averages from the requirement constants for local positions, counties, 1° quadrants, and States of the so-called winter wheat belt brought out some exceedingly interesting and significant features with special reference to local variations as indices to the selection of the best time for seeding in local regions, specific places, and in different years.

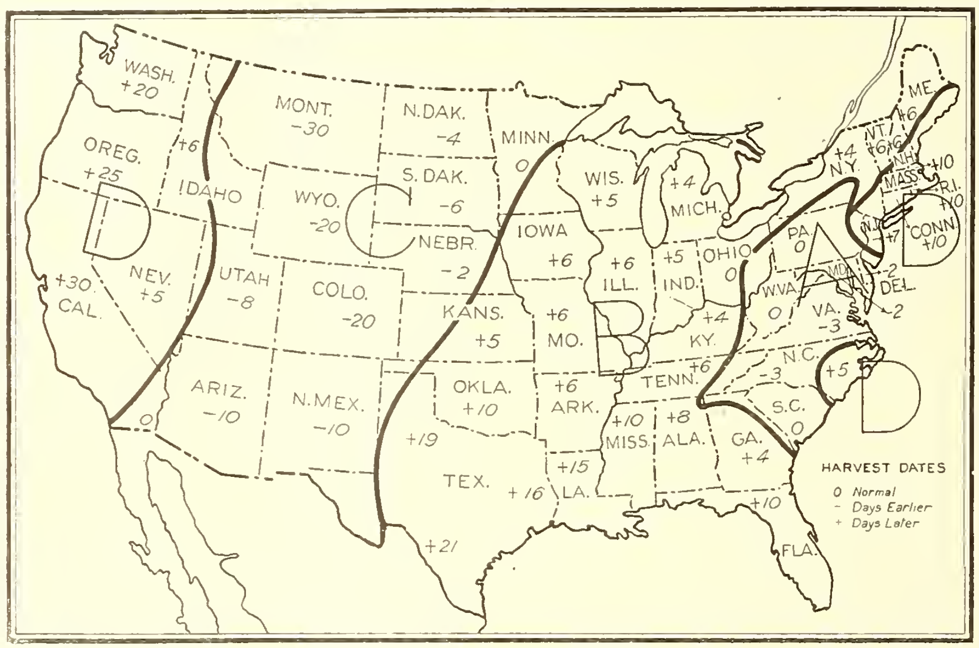

Figure 27.—Map of the United States with average variations for winter-wheat harvest dates by States and regions.

It was found by the 1° quadrants and average altitudes of record positions for West Virginia, that the average variations of the records from the requirement constants ranged from 1 to 2 days later for the beginning of harvest, principally for the lower altitudes, and from 1 to 8 days earlier for the higher altitudes; and that out of the 38 quadrants there were 6 with no variation, 10 with less than 3 days later, and 8 with less than 3 days earlier, and only 7 with more than 3 days earlier. For seeding, the later dates prevailed in 29 quadrants, with a range of from 1 to 14 days with the latest variation for the higher altitudes, and in 7 quadrants a range of from 1 to 6 days earlier, and 2 quadrants with no variation.

For altitudes between 500 and 2,400 feet the average of the departures from the requirement date constants for the beginning of harvest dates ranged from 0.5 of a day later for 800 feet to 9 days earlier for 1,800 feet, and for general seeding dates the average of the departures ranged from 0.9 of a day later for 1,000 feet to 14.5 days later for 2,400 feet.

Predicting Dates for Seeding Winter Wheat

The more important results of this study by the application of bioclimatic principles were in demonstrating (1) that the best *average time* in range of dates for seeding wheat in any local area or region of the United States within the range of winter wheat culture (as related to both the best practice in culture and in preventing serious damage by the hessian fly) can be predicted within a reasonable range of error; and (2) that with map calendars of *seeding date constants* for sea-level isophanes, giving ranges in altitudes above sea level, and a chart for finding isophane and altitude positions, *the average seeding date constant may be found within the given isophane and altitude range, and when this is corrected by the determined local early or late variation index* in days it will give the approximate average date and period within a range of 10 days as to the best time on the average to seed winter wheat within the local area represented by the given variation.

Why the Object was not Attained

While the map calendars for the principal wheat-growing States were issued in July 1917, their object was not attained because (1) the final published results of the investigations did not appear until the closing year (1918) of the war; (2) between the date of this publication in May and seeding time in the late summer and autumn of that year there was not time for the detailed information to reach the wheat growers, or for the required study and instructions to enable them to understand and properly apply the principles; and (3) by the seeding time of the following year the need for increased production had passed, and in later years the need was reversed in that reduced production was desirable and urged by agricultural economists.

Subsequent Research

Bioclimatic research since the publication of supplement 9 has shown that the fundamental principles as then outlined are sound and practical, not alone as applied to increased wheat production and hessian fly control, but as applied in (1) the interpretation of regions of normal and radically different retarding and accelerating influences on seasonal events of agricultural products and practice and on seasonal events in the life history of insects and other crop pests; (2) the determination for local areas and places the best time to seed or plant, the period of development of a crop, harvest time, types of products, geographic range and limits, and optimum zones and zonal types for specific products under the various controlling regional and local influences; (3) determination of the best time and methods under the varying regional and local influences to apply preventives and remedies in the control of insects and diseases; and (4) the selection of the type of product, type of agriculture, and type of economic practice and adjustment that is best adapted to a specific regional and local bioclimatic complex.

IN AGRICULTURE

In connection with the development of bioclimatic principles, systems, and methods, comprehensive studies have been made of the zone and zonal type distribution and centers of production of the principal agricultural products of the continents.

Some of the conclusions based on the results of studies of spring and winter wheat and other products are given here to emphasize the importance of the zonal and zonal type indices in agricultural research and practice.

The zones and zonal types represent the fundamental principle and basis for conclusions concerning the controlling causation-factor complexes and the varying modifying effects represented by the record limits and centers of adaptation of types of wheat and its culture.

ZONAL RANGE OF WHEAT CULTURE

Spring Wheat

The extreme range of spring wheat culture on a commercial basis in North America is from *a* zone major I minor −.4 and *w* type II .1 in Saskatchewan, Canada, to *a* zone II −.4 and *w* type .5 in Kansas; while in Europe the extreme range is from about *a* zone I .4 and *w* type II +2 in northeastern Union of Soviet Socialist Republics and *a* zone II −.3 and *w* type .1 in England to *a* zone II .4 to −4 and *w* type +.3 to −5+6 in Yugoslavia and Transcaucasia, and *a* zone II −.4 and *w* type .4 in Bulgaria.

Winter Wheat

For winter wheat the extreme range in North America is from *a* zone major II minor .1 and *w* type −.1 in Alberta, *a* zone −3 and *w* type −2 in the Columbia Basin in Washington, *a* zone .4 and *w* type −.2 in Oregon, *a* zone +2 and *w* type −2 in North Dakota, and *a* zone −2 and *w* type +3 in Michigan, to *a* zone II .6 and *w* type .4 in southern California, *a* zone II .7 and *w* type III .1 in Arizona, *a* zone II −6 and *w* type −6+7 in Texas, and *a* zone −5+6 and *w* type −4 in South Carolina; while in Eurasia and northern Africa the extreme range of general culture is from *a* zone II .3 and *w* type I −.4 in England, *a* zone II .2 and *w* type −1+2 in Sweden, *a* zone II +.2 and *w* type −3 in Union of Soviet Socialist Republics, *a* zone I .4 and *w* type II .2 at Tomsk, Union of Soviet Socialist Republics, *a* zone II −2 and *w* type +5 in Manchuria, *a* zone I .4 and *w* type II .3 in Amur, and *a* zone II −3 and *w* type +.4 in Japan, to *a* zone II −.6 and *w* type +.5 in Spain and about the same in Greece, *a* zone III +3, *w* type III −4, and *c* type III +3 in India, and *a* zone III .2, *w* type III −4, and *c* type III .1 in Egypt.

For the Southern Hemisphere the highest or poleward limit of commercial winter wheat culture in South America is in *a* zone major II .4, *w* type major I −4, and *c* type major II −.6; South Africa, *a* zone major II +.5, *w* type −2+3, and *c* type .6; New Zealand, *a* zone II .4, *w* type −1, and *c* type .6; while the lowest or equatorward limit in South America is in *a* zone III .1, *w* type II .6, and *c* type III −.2; in South Africa, *a* zone II .4, *w* type II −5, and *c* type III +1; and in Australia, *a* zone II +.7, *w* type II +6, and *c* type III +1.

CENTERS OF PRODUCTION

Spring Wheat

In North America the zonal centers of spring wheat culture by the *a* zone range from major II .1 in Manitoba to major II +.4 in Washington, while for the same positions the *w* types range from major II .2 to II +.4, and the *c* types from major I −3+4 in Manitoba to major II +.4 in Washington. The average annual rainfall for the given centers is about the same (10 to 20 inches), as interpreted from the maps, and ranges from 10 inches in Washington to 26 inches in Minnesota as the average for the record quadrants. The principal centers in Europe are in Russia, which

by the *a* zone range from II +.2 to +4, the *w* type from −3 to .4, and the *c* type from +1 to −.3, with about the same range in precipitation as in North America.

Winter Wheat

For winter wheat in the Northern Hemisphere the range of the centers of production in North America is from *a* zone II −3, *w* type −2, and *c* type .4 in Washington to *a* zone II .5, *w* type −.5, and *c* type −4 in Indiana, with an annual rainfall for the record quadrants of 20 inches in Washington and 43 inches in Indiana, which is also the range for all centers. In Europe the range of the centers is from *a* zone II .3, *w* type −2+3, and *c* type +. 3 in Union of Soviet Socialist Republics, to *a* zone II −.6, *w* type .5, and *c* type .7 in Sicily, with a range in annual rainfall of 10 to 20 inches in Union of Soviet Socialist Republics to 30 to 40 inches in Italy. The rainfall maps indicate that the principal amounts come in the summer. In Asia the range of centers in India is from *a* zone II .6, *w* type .6, and *c* type −.6, and *a* zone III +2, *w* type III −4, and *c* type III +.1 in the Punjab, to *a* zone III +.2, *w* type III −4, and *c* type III −.1 in the United Provinces, with the range in annual rainfall of from 9 inches in the Punjab to 30 to 40 inches in the United Provinces, and the principal rainfall in summer. In Egypt the center is in *a* zone III +1, *w* type II −.6, and *c* type III +1, with the annual rainfall for the record quadrant 1.3 inches, thus requiring irrigation at the time of sowing in November, again in December, and again before harvest in May and June.

In the Southern Hemisphere the principal centers in Argentina are in *a* zone II −.5, *w* type −3, and *c* type .6; and in *a* zone II −6+7, *w* type +.5, and *c* type III +1, with 20 to 30 inches annual rainfall. In South Australia the center is in *a* zone II .6, *w* type .4, and *c* type −.7; and in Victoria it is in *a* zone II +6, *w* type .4, and *c* type −6+7, with an annual rainfall of 20 inches for the record quadrant south and 20 to 30 inches in Victoria.

CONTROLLING FACTORS

The centers of production in acreage or quantity of wheat and other products are often controlled by factors other than those controlling the position and range of their optimum zone and zonal type. For example, a zonal center of wheat production in major III in India involves very different regional and local elements of influence from those of a center in the same zone in Egypt, or from those in major II of the United States, western Europe, South America, or Australia, but this does not indicate that, in general, the zone and zonal type are not the best indices yet discovered.

ZONAL TYPE INDICES

In this study the relations of the *w* warm and *c* cold month zonal types to the *a* zone indicate that in general (1) *the w type of major zone II, especially above minor 6, is more nearly representative of the zonal requirements of a given product than is either the a zone or the c type;* and (2) *the c type of major zone III, and often of minors 6 and 7 of lower II, is more nearly representative of the zonal requirements than is either the a zone or w type.*

The reason for this difference between the *w* and *c* type indices is in the fact that in major zones II and I, the warmest month is indicative of the growing period of the year, while in major III and lower major II it is the coldest month which is indicative of the optimum temperature during the period of principal growth of the product, provided the required rainfall comes in this period. There are, of course, exceptions to this general rule where the summers are too cold or too hot, or the winters too cold for the product, or in regions where precipitation is the controlling factor rather than temperature.

COMPARATIVE TEMPERATURE AND VARIATIONS

Example 33 shows that (1) for the north-poleward limit in England the *w* record indicates that it is too cold for wheat culture, but due to the relatively warm *c* mean wheat is grown; (2) for Amur the *a* and *c* records indicate that it would be much too cold, but with a high *w* mean wheat can be grown; and (3) in the equatorward limit the *a* and *w* record means, as compared with an optimum of *a* 55° and *w* 74°, indicate that it is too hot, but with the record *c* mean (as compared with an equatorward *c* optimum of 60° to 74°) coming in the cooler months of principal growth, wheat is grown.

The variations from the constants are significant in showing that for England the *a* and *w* records are very much colder than their constants, with the *c* colder than its constants but relatively warmer than *a* and *w*; for Amur the *a* and *c* are colder and the *w* much warmer; for India the records are slightly warmer but near the constants; and for Egypt the *a* and *c* are colder and the *w* slightly warmer than their constants.

It is to be kept in mind that *there is an important difference in comparing the records of two places, and comparing records with their constants*, since the first simply indicates a range in temperature, while the latter gives the variation as a measure of the relative intensity of modifying regional and local influences.

Example 33.—*Comparison of temperatures and variations in degrees Fahrenheit of the extreme range of winter wheat culture in four representative areas*

	sym	England			Amur		
		pc	*pr*	*var*	*pc*	*pr*	*var*
		°	°	°	°	°	°
Poleward limit	*a*	65. 13	47. 50	−17. 63	38. 44	30. 00	−8. 44
	w	83. 50	58. 00	−25. 50	62. 75	70. 00	+7. 25
	c	46. 75	37. 00	−9. 75	14. 13	−8. 25	−22. 38
		India			Egypt		
Equatorward limit	*a*	82. 02	82. 17	+0. 15	83. 90	79. 07	−4. 83
	w	89. 78	90. 00	+. 22	89. 85	90. 00	+. 15
	c	74. 25	74. 55	+. 30	77. 95	58. 00	−19. 95
Range	*a*	16. 89	34. 67	17. 78	45. 46	49. 07	3. 61
	w	6. 28	32. 00	25. 72	27. 10	20. 00	7. 10
	c	27. 50	37. 55	10. 05	63. 82	66. 25	2. 43

CENTERS BY ZONES, TYPES, AND TEMPERATURE

In example 34 it is shown that (1) the range in temperature between the lowest and highest for the four centers in major zone II is only 11° for the annual mean, 16° for the mean of the warmest month, and 18° for the mean of the coldest month; (2) the optimum *a* mean temperature in major zone II is from about 51° to 62°, with an average of 54°; for the *w* mean from 65° to 81° with an average of 74° to represent the optimum for the warmest month and principal growing period in zone II, and for the *c* mean from 27° to 45°, with an

average of 35°, while in zone III in India it is 77° for the *a* mean, 90° for the *w* mean, and 60° for the *c* mean, with the latter representing the optimum for the cooler months of the year and principal period of growth; and (3) the zones and temperatures of the Tomsk, Siberia, quadrant in comparison with other poleward extremes show that the *w* mean is the same as that in France, only 8° colder than in Hungary, and only 16° colder than in the Punjab quadrant. So it would appear that *w* 65° will serve as an index to the poleward or alpine limit of optimum winter wheat production, about *w* 74° as the index to the optimum for maximum production in zone II, and about *c* 60° as an index to the optimum for maximum production in zone III. According to this and other examples it would appear that the zonal index for the optimum in major II would be *a* zone minor .4, *w* type .4, and that in major III, with special reference to high level positions, the optimum would be *c* type .1.

EXAMPLE 34.—*Principal centers of winter wheat production by zones and zonal types, and corresponding temperatures in representative 1° quadrants*

Geographic regions	Zones		Zonal types				Temperature					
	a		*w*		*c*		° F.			Average		
	Ma	*Mi*	*Ma*	*Mi*	*Ma*	*Mi*	*a*	*w*	*c*	*a*	*w*	*c*
Kansas, United States	II	+5	II	−5+6	II	.4	55	79	30	----	-- -	---
France	II	.4	II	.2	II	+6	51	65	39	- --	----	----
Hungary	II	.4	II	.4	II	+4	51	73	27	----	---	----
Punjab, India	II	.6	II	.6	II	−.6	62	81	45	54+	74+	35+
United Provinces, India	III	+.2	III	−4	III	−.1	77	90	60	--	----	60
Range in temperature in major II	-- -	---	----	--- -	----	-----	11	16	18	----	----	----
Range in temperature in majors II and III	----	----	----	------	----	-----	26	25	33	----	*w*	----
Tomsk, Siberia, extreme	I	.4	II	.2	I	−3	30	65	−2	----	65	- --

For spring wheat is was found that the optimum for the northern hemisphere is indicated by an average of *w* 69°, representing zone II *w* type −.3, as compared with that for winter wheat *w* 74°, representing zone II *w* type .4 as the optimum. For wheat in the northern hemisphere the optimum by the *c* mean in zone II is below −.6; and in III the optimum is 60° for the extreme and 53° for the center of production, with an average of 56° as the optimum index, representing zone III *c* type +.1. For the southern hemisphere the *w* average is 71°, representing zone II *w* type +4, while for the *c* mean the average is 53°, representing zone II *c* type −7.

RELATION OF TEMPERATURE

These studies show that the fundamental principles in regard to the temperature and the thermal zones and types as indices to successful types of agricultural products are:

1. Temperature, in connection with precipitation and relative humidity, serves as the fundamental guide to the interpretation of factors which control the geographic and zonal distribution of products in general, because (1) the range in average annual temperature is an index to the major and minor zones; (2) heat and cold, as represented by the means of the warmest and coldest months of the year are indices to the warm and cold zonal types; (3) the relative amount of precipitation is an index to the precipitation types; and (4) it is through the zone and its types for representative positions and quadrants that the poleward, alpineward, and equatorward zonal range and centers of adaptation of given products are determined.

2. In some respects the precipitation type of a zone is more important than the *w* or *c* types, because, while the annual temperature, or that of the warmest or coldest months, may be favorable in a given arid, subarid, or sub-humid region of major zones II or III, crops can be grown only with the required amount of water supplied at the right time either by rainfall or artificial irrigation.

3. There are many other elements of *effect*, as manifested by plant and animal life, climate, weather, etc., which serve to characterize specific or general zonal types, just as there are also many elements of *cause* in the general physiography, topography, soils, and bodies of water, which, separately or combined, serve to characterize specific causation-factor types of a local area or general region. Thus, in any comprehensive study and analysis of the zonal and zonal type requirements of a product or of given classes of products, it is important that as many of these cause and effect types should be considered as possible.

4. Because the major and minor zones are based on, and characterized by, ranges in the average *annual* temperature over a period of years, they are designated as *a* zones.

5. Because the principal thermal types of the *a* major and minor zones are based on and characterized by the average of the mean of the *warmest* month or by the average of the mean of the *coldest* month they are designated as *w* and *c* zonal types.

6. As a general rule the *w* type of a given *a* zone is the most important thermal index to the zonal requirements of a product of the minor zones 1 to 5, inclusive, of major II; and the *c* type is often the most important index to the zonal requirements of minor zones 6 and 7 of major II and certainly of all of the minor zones of major III.

7. The fundamental basis for the interpretation of the *a* zone and the *w* and *c* types is formed by the records of the position, area, or region referred to appendix table 3, because this table gives the standard thermal requirement constants of the bioclimatic law relative to the *a* zone and the *w* and *c* zonal types.

GROWING SEASONS

In any study of the zonal distribution and limits of agricultural products, it is essential to consider the length of the growing seasons as related especially to major zone II and to its minor zones 1 to 7.

The so-called growing season varies in length and character with the latitude, altitude, and with the regional and local physiographic features. Four astronomic seasons of 3 months each with a 9-month warm or growing season occur, in a general way, in the mid-minor zone 4 of major II but do not occur in major I, with its perpetual winter, or in major III, with its perpetual summer. Even within the range of major zone II of the Northern and Southern Hemispheres, the length of the warmer or growing season varies from 2 months or less in its higher latitudes and altitudes to 12 months in its lower latitudes at or near sea level.

For the successful production of agricultural products, there are certain elements of climate and weather in the various growing seasons which are essential. Among these elements is temperature, in which too much heat or too much cold is fatal to certain plants or animals; while somewhere between the extremes each

organic species, variety, or type finds an optimum range for its normal growth and reproduction. Thus each has its optimum growing season, controlled by short or long periods of optimum conditions. The planting, growing, and harvest seasons also are controlled by temperature.

The weather elements of primary importance to plant and animal products are rain and sunshine in required amounts during the growing season. Each and all of these essential elements of temperature, rainfall, sunshine, etc., serve to characterize the zones and zonal types.

By means of bioclimatic principles and methods, these elements of the growing season can be analyzed for specific places within a local area, region, country, or continent. Moreover the analyses of the elements of one place may be compared with those of another on a strictly coordinate basis.

Since the minor zone and its zonal climatic, seasonal, and cultural types can be determined for record positions and indicated for nonrecord positions, and since the zone and its types serve as reliable indices to the essential elements of the growing season, by the bioclimatic method much of the essential information about a place or local region is made immediately available for interpretation and application.

THE THERMAL INDEX

As has been shown in example 6 and in more detail in example 71 to 75, the length of the warmer and growing season can be readily interpreted by the thermal index method.

THE KILLING-FROST INDEX

The usual method of defining the growing season is by the average dates of the late killing frosts in spring and the early frosts in autumn, as derived from records at meteorological stations. This frostless-season method serves as a general guide to the crops that can not be grown except during this period in any given section of the country and is of special importance in upper major zone II. It becomes less important, however, as one approaches the subtropical zones, except as related to a limited number of crop plants which require the longest possible period for their development to the harvesting stage, e. g., sugarcane. A large percentage of the crops of the temperate zones, however, do not require the full frostless period for development except toward their poleward limit. There are also certain plants which are, or have become, so resistant to frost (and even freezing) that their season of growth begins long before the latest killing frost in spring and continues long after the earliest killing frost in autumn, e. g., wheat, rye, grass, and a number of flowering plants.

Variation in the Frostless Period

There is often a wide variation in the period between killing frosts in the same general locality; near Parkersburg, in 1923, the first killing frost occurred on October 13 in the lowlands 3 or 4 miles back from the protecting influence of river fog, but it was not until October 19 that tender vegetation was killed in the river valley, including Kanawha Farms and the grounds of the Base Station, while in Parkersburg such plants as dahlias, cannas, and tomatoes were not killed in protected places until the freeze of November 10. There is thus a difference of nearly a month in the time of the first killing frost within a distance of about 10 miles from the meteorological station at Parkersburg. The average date of the first killing frost in autumn for this general base area is October 13, but there is a wide range of seasonal variation for any local area, so that frost maps giving the average date for a given station or region can serve only as a broad general guide to the time when killing frosts may be expected. Thus, while the frostless season may serve as a general guide to the selection of certain long-season crops for the lower minor zones of major II or of short-season crops for the higher minor zones, there are many products for which the length of the frostless season is of little or no consequence.

THE PHENOLOGICAL INDEX

It is well known that (1) each species and variety of wild or cultivated plant has its own short or long growing season, as from germination or beginning of growth to flowering, fruiting, harvest, death, or rest; (2) the required length of the period for different species and often for different varieties of the same species in the same locality, may vary from less than 2 months for development to the harvest or fruiting stage for short-season types to more than 8 months for long-season types; (3) for a given locality a considerable percentage of cultivated plants do not require the full length of the average frostless season; (4) the full length is required by only a small percentage; and (5) some have a very much longer season of growth than that defined by the average dates of spring and autumn killing frosts.

With the wide range of difference in the length of frostless seasons, even in the same general locality, and the wider range of seasonal requirements of cultivated plants, it is obvious that *the best index to such seasonal requirements is in the average dates of the seasonal events of the plant itself.* In other words, the seasonal history of the plant rather than frost or any other records of climate or weather is the true guide to its seasonal requirements, because (1) *no matter how wide the distribution of a plant or animal may be poleward, equatorward, or alpineward, or how restricted it may be to special conditions, its seasonal events will serve as a reliable index to its seasonal, zonal, or zonal type requirements and limits;* (2) observations and records of seasonal-history events of a plant or animal apply to the specific locality and place where they are made; and (3) comparison of record dates of the more important events of a plant, as observed within a given zone and zonal-type range on one continent, will indicate its probable adaptation and range in the same zones and types on another continent.

Thus recorded dates of representative seasonal events of a plant or animal from widely distributed geographic positions serve the same purpose as, and much better than, temperature records, for the interpretation of its specific and general climatic, zonal, and type requirements.

SEASONAL EVENTS IN PLANTS

The more important seasonal events in plants are (1) the beginning of growth in the spring, such as the opening of leaf buds and unfolding of leaves, opening of flower buds and flowers, etc.; (2) the progress of growth in summer, such as the flowering of certain plants or the maturing of the foliage of others, and the ripening and harvest of grain, fruit, and garden crops; and (3) the ending of plant activity in autumn, such as the first, maximum, and last coloring and falling of the foliage of deciduous trees, and the last flowers of late-flowering plants.

SEASONAL EVENTS IN ANIMALS

The events in animals to be noted include such conspicuous occurrences as the first appearance of certain birds and insects in spring, their seasonal activities or seasonal history during the spring and summer, and their last appearance in autumn.

In economic entomology the seasonal events of insects, the number of generations, and the time to apply control measures are of fundamental importance as related to zones, zonal types, and length of seasons.

SIMPLICITY OF THE PHENOLOGICAL METHOD

Using phenological principles and methods of observation it is a simple matter for anyone who is a good observer and accurate in keeping records to determine for himself the essential features of the seasons of his immediate locality relative to any product or type of production.

The most important element in phenological records is the average date of the selected event for a period of years (the longer the better but 5 to 10 are sufficient) because the record dates for any given season compared with the average or constant is one of the best guides to indicate whether a given season is relatively late or early.

By this method it will be found that the phenological season of many native and cultivated plants is not determined by frost but by their ability to resist the effects of low temperature. It will be recognized also that there are many other requirements of a given plant, such as moisture, length of day, topography, soil, type of climate, and ecological associations with other plants and animals adapted to the same environment; each of these factors influences the seasonal activities, so that the seasonal history of a species or variety, or even of an individual, represents the effect of the factor complex of its immediate environment and thus serves to give the essential information concerning its culture or control.

In interpreting phenological observations or records it must be kept in mind that there is often such a wide range between early and late varieties of the same species of a plant, that it requires experience and the exercise of good judgment to select representative individuals for observation, just as it does to distinguish the normal from the abnormal as to both the event and the cause.

OPTIMUM SEEDING AND HARVEST TIME

One of the important applications of the phenological principle is in the selection of the average optimum seeding time for a given plant in a given locality. Through observations, experience, and experimental tests, certain selected plants are utilized as indices to the progress of the seasons, and as criteria for the best time for seeding spring wheat, oats, barley, and many other crop plants in the spring, for seeding winter wheat and rye in the autumn and for planting fruit trees and shrubs.

From year to year and from season to season, there is a greater or less variation in dates from the given average or requirement constant for each subject, but whether the season is abnormally early or late, the date of an index event will serve as the best guide to the best date or period of dates for seeding or planting, to the time when the harvest may be expected, and to the length of the season for each species or variety of crop plant.

RELATION OF THE PHENOLOGICAL SEASON ZONES AND ZONAL TYPES TO RESEARCH AND PRACTICE

As with given ranges of temperature, the average dates and periods of the outstanding events in the seasonal history of plants and animals serve to characterize not only the zone and zonal type but also the season type for a given place or region. In fact *the phenological index is, in general, the most reliable basis for the interpretation of the zonal season type for a given farm or field.*

Phenological principles and methods are of the greatest importance in research and practice relative to the seasons of agricultural products; and since phenology depends to a great extent upon temperature, it may be said that the concept of the science of bioclimatics is based largely on phenological evidence.

PART 2. TIME, SEASONS, ZONES, ZONAL TYPES

THE ELEMENT OF TIME IN BIOCLIMATICS

Since time in days, dates, and years is the basic element in the development of the sciences of bioclimatics and phenology, a comprehensive study has been made of its relation to the two other basic elements, temperature and distance, and to the other sciences. A detailed discussion of this subject is omitted here.

The principal subjects considered were (1) the basic laws and principles of time and the rotation and revolution of the earth and the inclination of its axis; (2) the rotation of the earth and the progress of hours, days, and dates; (3) the international date line; (4) month and year-date calendars; (5) the revolution of the earth and inclination of its axis and progress of time by year-dates; (6) rates of progress with distance in degrees of the orbit by periods between the equinoxes and solstices; (7) rates of progress with the inclination of the earth's axis relative to distance in degrees of latitude between the tropical circles and between the poles; and (8) relative length of day and night for periods between the equinoxes and solstices in sums of 12-hour units for representative latitudes between the Equator and the poles according to a law of day and night time.

In bioclimatics there is seldom need for a smaller unit of time than the 24-hour day as applied to seasonal and other periods between month and year-dates of the calendar, the computation of date and period constants, the determination of the daily rate of movement of time per unit of distance by terrestrial latitude, isophane, altitude, or of degrees of the orbit, increase and decrease in the length of day and night time, and such other elements of time as may be involved in the phenomena of life and climate.

The month or year date of the calendar serve as the basic *time constants* for (*a*) all records of variable events of the year by dates and periods; (*b*) computation of date and period constants; (*c*) rates of movement by dates; and (*d*) the determination of variations of the recorded variable from the requirement constants of bioclimatic law; all of which are fundamental in the study of problems in variable nature whenever the element of time is involved.

VARIATIONS IN THE LENGTH OF DAY AND NIGHT TIME

While the hours and the standard calendar day of 24 hours of mean solar time are always the same from pole to pole, the hours of actual day and night time are never exactly the same in different latitudes, except on the dates of the equinoxes, because the inclination of the earth's axis relative to the fixed position of the sun is constantly changing as the earth revolves in its orbit. Thus the length of daylight varies from 12 hours everywhere on the day of the equinoxes, and from near 12 hours between the tropical circles to about 6 months at the poles, with alternating periods of about 6 months of night and 6 months of day at the North and South Poles.

DAY OF THE WEEK, MONTH, AND YEAR

It is only at midnight on the international date line that the day of the week, month, and year are the same on all meridians, because as soon as this meridian passes the position of the midnight hour it is another day and later date on the east side of the line, and at all hours of the day the dates differ 1 day to the east and west of it until it returns in 24 hours to its midnight hour. While the difference in hours and dates on the opposite side of the date line from pole to pole is always 24 hours by the calendar, the difference in time of day between meridian 180 and any other meridian may range from a few minutes to any number of hours within the 24, so that the hours gained say to Monday on one side, and lost to Sunday on the other, is the difference in time between the hour of this meridian and the midnight hour on any other meridian.

COMPUTING TIME BETWEEN DATES AND RECORDED EVENTS

Fractions of a day are disregarded in bioclimatics for the computation of differences in time between recorded dates of events. Thus all computations are made as if there was *a difference of 24 hours between observations on 1 day and those of the next*, because a period of 24 or even 48 hours is well within the range of allowable error in observing and noting the exact time of occurrence of variable and slowly developed events in the seasonal phenomena of plants and animals, as for example, the opening of leaf or flower buds, the unfolding of leaves, the general planting and harvest dates of crops, beginning and ending of the local seasons, and the many other variable events in natural phenomena.

The Year-Date Calendar

In bioclimatics the calendar for a year of 365 days with year-dates from 1 to 365, inclusive (schedule 4), is adopted but is arranged in such a way as to facilitate the finding of the month date for any given month. In the use of this calendar the fraction of one-fourth or 0.25 of a day for a single year, or 1 day in 4 years may be disregarded because it is not possible to distinguish the difference in the progress of an event in a fraction of a day for 1 year or a whole day in 4 years. In fact the calendar for leap year and the year succeeding it provides for the additional day of time and thus is represented in the recorded date of a given event in any leap year.

THE REVOLUTION OF THE EARTH IN ITS ORBIT

The progressive movement of the days of the year during one complete revolution of the earth in its orbit is measured in degrees of the ecliptic or of the orbit, and since the mean solar year from the March equinox is 365.242 days, and the distance covered is 360° of the orbit, the average rate of movement is (365.242÷360) 1.0145+ days to 1°.

Since, however, the earth's orbit is an ellipse, the time required to cover the same number of degrees varies from the average with the distance of the earth from the sun at different times of the year. These variations are represented by the different lengths of the periods in days between the dates of the equinoxes and solstices. Thus, beginning with zero

in the orbit and the date of the March equinox March 20 at midnight, the periods of time as related to distance in orbital degrees are as in example 35.

EXAMPLE 35.—*Time and distance with rates of movement in the orbit between the equinoxes and solstices*

Orbit	Colures	Dates		Period	Distance	Rate
		md	*yd*	*Days*	*Degrees*	*Days*
0	Equinox	Mar. 20	79			
90	Solstice	June 21	172	93.078	90	1.0342
180	Equinox	Sept. 22	265	93.078	90	1.0342
270	Solstice	Dec. 21	355	90.048	90	1.0005+
360	Equinox	Mar. 20	79	89.038	90	.9893+
		Year		365.242	360	[1] 1.0145+

[1] Average.

day to the fourth decimal; and finally is given the average rate in days per degree for the year.

Figure 28*A* shows how the major motion of the earth during one complete revolution around the sun is measured in dates and periods of the calendar and how these dates correspond with distance in degrees of the orbit. Its elements are: *Orbit degrees*, the degrees of the orbit in the upper scale at intervals of 9° from 0 to 360, with the corresponding vertical light lines representing celestial longitude and the heavy lines *EC* and *SC* the equinoctial and solstitial colures; *Latitude North* and *South* gives the degrees of terrestrial latitude in the scale to the left at intervals of 10°, with the horizontal lines representing parallels on the plane of the earth's axis from pole to pole relative to the plane of the orbit or ecliptic. On the line of the North Pole

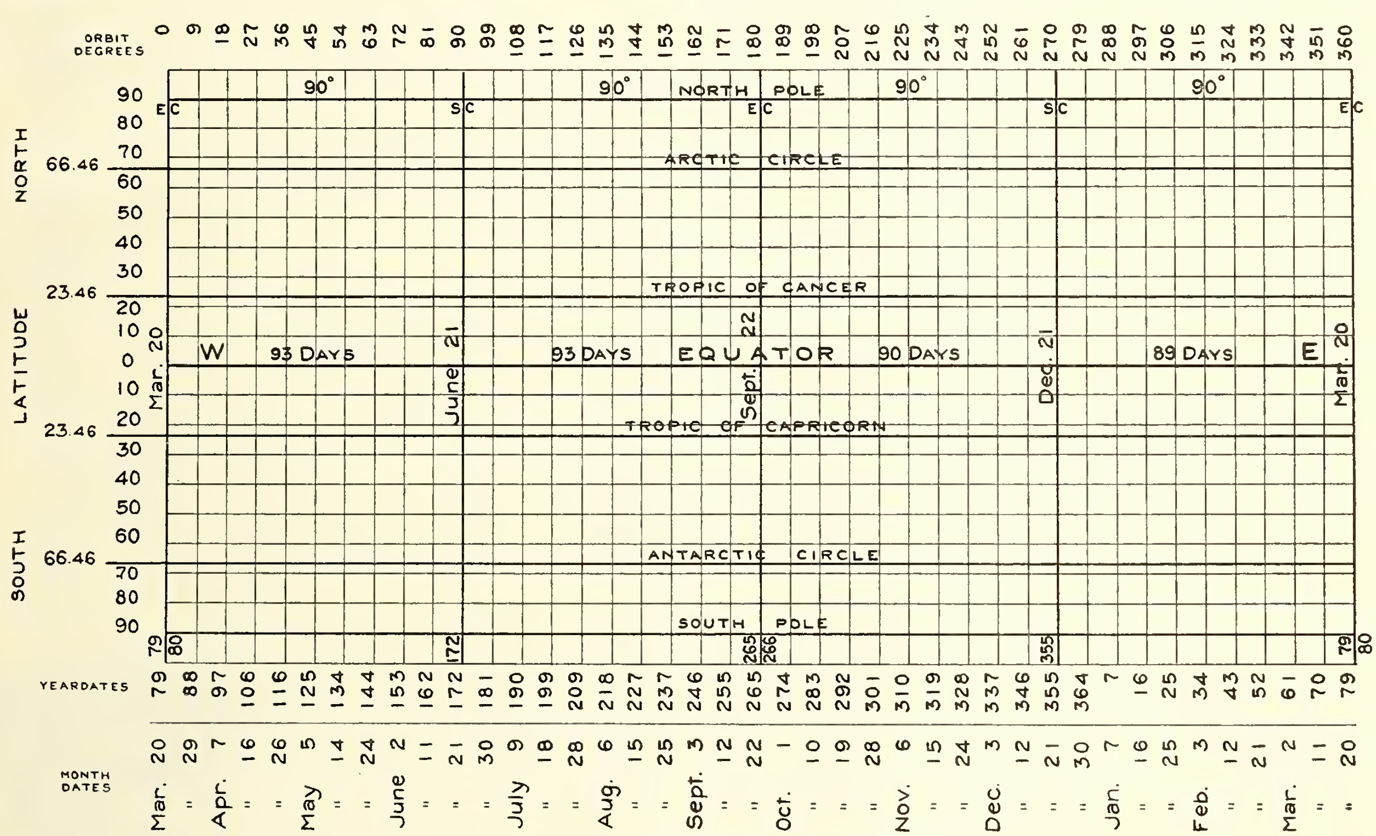

FIGURE 28*A*.—Time and the revolution of the earth in its orbit.

In example 35 the average date of the March equinox is assumed to occur at midnight March 20 on the equinoctial colure and terrestrial meridian 180° with the event occurring March 21 at 6 a. m. on meridian 90 E, noon at Greenwich, 6 p. m. on meridian 90 W, etc. Thus from midnight March 20 to midnight or any hour on June 21 is (*yd* 172—*yd* 79) 93 days, and so on until midnight March 20 of the next year as shown. *Orbit* gives the degrees of the orbit at intervals of 90° from 0 to 360; *Colures*, the equinoctial and solstitial colures; *Dates, md* month dates and *yd* year-dates of the calendar; *Period days*, the periods in days and fraction of a day corresponding to the fraction of a day over 365 days, or in other words the relative proportion of the fraction of time for the distance of 90° covered; *Distance degrees* gives the degrees of the orbit for each interval of time; and *Rate days* gives the rates per degree in each period in units of a 24-hour day and fraction of a day are given the intervals of 90° between the colures, and on the equatorial line the corresponding period in days between the equinoxes and solstices, with their month and year-dates on the colural lines. The North and South Poles, Arctic, Antarctic, and Tropical Circles, and Equator are represented by heavy lines. In the scale below are given the year-dates and month-dates for the given orbit degrees and celestial longitude from the March equinox of 1 year to the same date of the next, as in appendix table 12. As represented in this chart, the movement of the earth is from west (W) to east (E) through 360° at the average rate as given in example 35.

MOVEMENT BETWEEN THE TROPICAL CIRCLES

The rate of movement in 24-hour days per degree of latitude is determined by dividing the distance in degrees by the time occupied in days, as in example 36.

Example 36.—*Time and distance with rates of movement between the Tropical Circles*

Latitude	Dates	Colures	Period	Distance	Rate
			Days	*Degrees*	*Days*
0.000	Mar. 20	Equinox			
23.468 N.	June 21	Solstice	93.078	23.468	3.9661+
.000	Sept. 22	Equinox	93.078	23.468	3.9661+
23.468 S.	Dec. 21	Solstice	90.048	23.468	3.8370+
.000	Mar. 20	Equinox	89.038	23.468	3.7940+
	Year		365.242	93.872	[1] 3.8908+

[1] Average.

Fractions of a Day and Degree

Since the average year is 365.242+ days and the Tropical Circles are 23.46° from the Equator, the computation of rates involves fractions of a day; these fractions (at least to the second decimal) are utilized in computing date constants, but the dates as included in the tables and charts are given in full days. While this involves an error of a fraction of a day at varying intervals of degrees, it serves the purpose of illustrating the principles and laws involved in bioclimatic research and practice.

Example 36 differs from example 35 in that the distance is in latitude. *Latitude* gives zero for the Equator, 23.468 N. the Tropic of Cancer, and 23.468 S. the Tropic of Capricorn; *Dates*, the calendar mean month dates of the equinoxes and solstices; *Period days*, the period in days between the dates (as June 21 minus Mar. 20 equals 93); *Distance degrees*, the distance in degrees of latitude; *Rate days*, the rate in days and fraction of a day to 1° of latitude; and finally the average rate per degree for the total time and distance.

The object of this example is to find the rate of movement in time to the distance represented by the inclination of the North Pole of the axis toward the sun between the March equinox and the June solstice, and the inclination of the South Pole between the June solstice and the December solstice, and the North Pole back to the March equinox. Another important object of example 36 is to make the rates of movement available for application in computing date and period constants of appendix table 13 and to serve as a basis of reference to, and comparison with, date and period constants of other movements in time with special reference to the laws of the seasons as described further on and under table 13.

Figure 28*B* will serve to illustrate the principle of the movement of time relative to the inclination of the earth's axis between the Tropical Circles, as measured in whole days of the year in accordance with table 13 and the standard year and month dates.

The object of this chart is to show (*a*) the movement of time between the Tropical Circles with the inclination of the earth's axis during a complete revolution of the earth in its orbit as measured in dates and periods of the calendar; (*b*) how the inclination motion by degrees of terrestrial latitude is coordinated with the movement of time by degrees of the earth's orbit; and (*c*) how the astronomical seasons, as defined by the equinoxes and solstices, apply alike to all celestial longitude and terrestrial latitude from pole to pole.

The basic elements of this chart are the same as in figure 28*A*, with the *a1*, *b1*, and *c1* lines added to represent the orbital and inclination movements and movement by degrees of latitude in the *a1* north-poleward from the Equator to the Tropic of Cancer, *b1* south-poleward from the Tropic of Cancer to the Equator and on to the Tropic of Capricorn, and *c1* north-poleward from the Tropic of Capricorn back to the Equator in 1 year of time and a total distance of 93.872° of terrestrial latitude and 360° in the earth's orbit; *EC* represents the equinoctial and *SC* the solstitial colures with their corresponding dates from pole to pole. The periods in days between *EC* and *SC* are the astronomical or tropical seasons of *1* 93, *2* 93, *3* 90, and *4* 89 days of the 365 days of the year with the fraction of a day omitted in each.

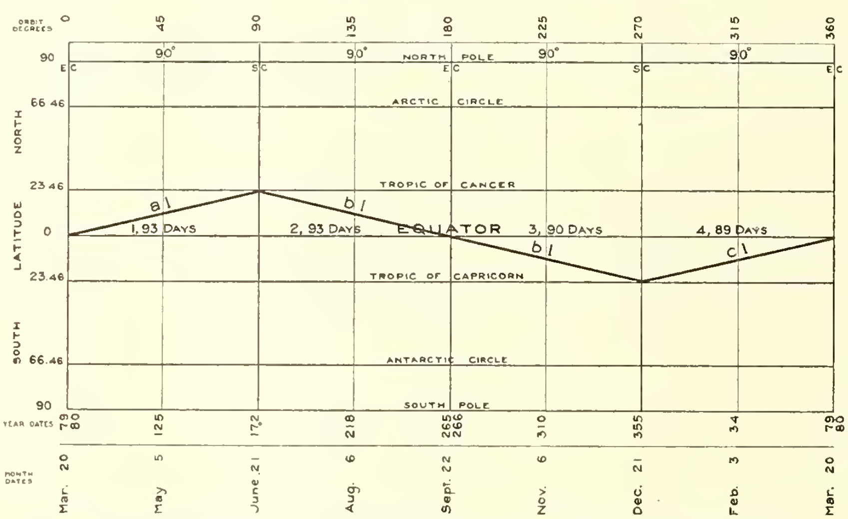

Figure 28*B*.—Inclination of the earth's axis and movement of time between the Tropical Circles.

The significant features of this chart will be brought out in more detail in a further discussion of the complete coordination of the orbital and inclination motions and movements in time as measured in dates of the calendar.

It will be seen, however, that while the earth's revolution is at the rate of about 1 day to 1° of its orbit, the inclination of the axis relative to the vertical sun and the movement between the Tropical Circles is at the rate of about 4 days to 1° of latitude, yet at the same time, as shown by the dates of the equinoxes and solstices, the dates for a given latitude in the inclination movement agree exactly with the date for a corresponding degree of the orbit, as March 20 orbital 0 and terrestrial latitude 0; June 21, orbital 90, and latitude 23.46 N.; September 22, orbital 180, and latitude 0; and December 21, orbital 270, and latitude 23.46 S. Thus

taking the longitudinal lines of the chart as representing degrees of the orbit and the movement of time west to east by dates, and the latitudinal lines to represent degrees of latitude north and south of the earth's Equator, the lines, *a1*, *b1*, and *c1* at the given angles between the equinoctial and solstitial colures will give the same dates for both latitude and the orbit at the point where the colure or orbital and latitudinal degree and date lines intersect, as line *b1* intersects the Equator in orbit degree 180 on September 22.

In any consideration and comparison of the tables and charts of the progressive movements of time relative to astronomical, astroterrestrial, and terrestrial seasons of the year it is important to keep in mind this principle or the law of orbital and inclination movements in time with distance in degrees.

MOVEMENT BETWEEN THE POLES

With the dates always the same from pole to pole on the colures for each equinox and solstice during one complete revolution of the earth, the rates of movement in time per degree of latitude from the date of the December solstice at the South Pole to the date of the June solstice at the North Pole, and back again to the December solstice at the South Pole is the time occupied (365.242 days) divided by the distance (360°) covered, as in example 37 (see fig. 30).

Example 37.—*Time and distance with rates of movement between the poles*

Latitude	Dates	Colures	Period	Distance	Rate
			Days	*Degrees*	*Days*
90 S.	Dec. 21	Solstice			
0	Mar. 20	Equinox	89.038	90	0.9893+
90 N.	June 21	Solstice	93.078	90	1.0342
0	Sept. 22	Equinox	93.078	90	1.0342
90 S.	Dec. 21	Solstice	90.048	90	1.0005+
180+180	Year		365.242	360	[1] 1.0145+

[1] Average.

In example 37 the rates in days per degree of latitude are exactly the same as the rates in days per degree of the earth's orbit as given in example 35, because the total distance in degrees of latitude covered in 1 year between the poles is 360°, which is the same as the distance in degrees of the earth's orbit covered in the same time.

The object of this example is to show the relations between the rates for the polar movement and the tropical movement of example 36, in which the same dates and periods of time are involved over a much narrower latitude; also to make the rates available for computing a table of date and period constants as given in appendix table 14. The constants of tables 12, 13, and 14, together with tables 15 and 16, as will be seen, are of both scientific and practical importance in studying the time element of bioclimatics.

RELATIVE LENGTH OF DAY AND NIGHT TIME

The relative length of day and night time during the year in different latitudes between the terrestrial equator and the poles is purely an astronomical phenomenon in cause and effect of the laws of the motions of the earth and the progress of time.

CAUSE

As is well known, the 24-hour day is caused by, and is a measure of the time required for one complete rotation of the earth on its axis, while the relative length of day and night time from sunrise of one to sunrise of the next succeeding day in any given terrestrial latitude is controlled by the inclination of the earth's axis, while the length of the year is controlled by one complete revolution of the earth in its orbit.

EFFECTS

The general effects of these primary causes are (1) more hours of daytime and corresponding less hours of nighttime between the dates of the March and September equinoxes from the Equator to the North Pole, and during the same period the reverse more hours of night and less hours of daytime from the Equator to the South Pole; and (2) between the dates of the September and March equinoxes less hours of day and more hours of nighttime from the Equator to the North Pole, and during the same period of time the reverse, more hours of day and less hours of nighttime from the Equator to the South Pole.

This increase and decrease in the hours of day and night time represents movements in time—corresponding to the movement in days and dates of the months of the calendar year—between the dates of the beginning and ending of the astronomical seasons for all latitudes, and to the movement in time with distance in degrees of the earth's orbit relative to the length of the astroterrestrial seasons in *given latitudes*, as will be explained in more detail further on.

CONSTANTS AND VARIABLES IN DAY AND NIGHT TIME

Just as the dates of the equinoxes and solstices and the periods between them may be considered as astronomical constants—as related to celestial longitude—the 24-hour day is a constant as related to terrestrial longitude, while the relative length of day and night time is a variable as related to latitude between the equator and the poles.

It is true that there are a number of intricate astronomical variations in the motions of the earth and corresponding variations from the 24-hour day during the year and periods of year, but these are of little or no significance as to effects on bioclimatic phenomena.

In the computation and comparison of the relative length of day and night time for given latitudes between the equinoxes and solstices the 12-hour instead of the 24-hour unit has been adopted for application in bioclimatics, because on the date of an equinox there are 12 hours of day and night in all latitudes from pole to pole, but between the dates of an equinox and a solstice the hours of daytime vary from 12 hours at the Equator to 6 months at the poles; thus the difference in hours between day and night is best expressed in 12 hours.

INCREASE AND DECREASE IN SUMS OF DAY AND NIGHT TIME

Owing to the fact that the sums of day and night time vary not only with the different astronomic periods but with different ranges in degrees of latitude, it was not practicable to adopt a system of *unit constant rates* of increase and decrease. It was found, however, that the sum of hours of daytime between the dates of the equinoxes and solstices for given latitudes divided by 12 hours gave a sum of 12-hour units of daytime which answered the purpose of finding the *sum constant* for given latitudes.

By this method the sum of 12-hour units included a fraction of a unit, but as explained further on under appendix table 15 the determined sums of units are designated as constants in even units to include fractions above and omit fractions below 0.5 of a day or 6 hours.

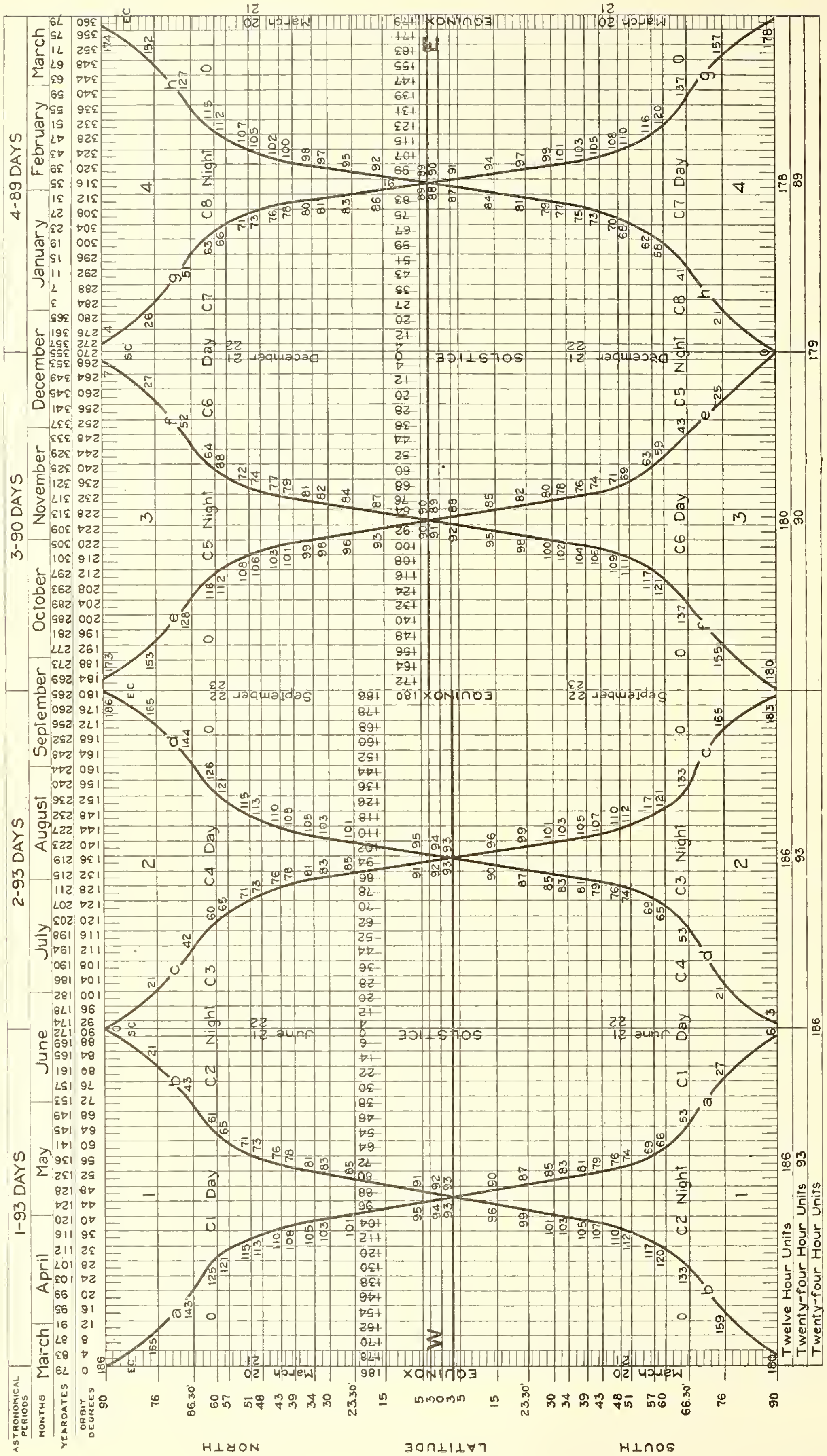

FIGURE 29.—Chart to represent the law of day and night time.

It is by this principle of sums of 12-hour units of day and night time for each of the four astronomical periods, or so-called seasons, in different latitudes that problems of the relations of length of day to biological and seasonal phenomena may be best considered, studied, and solved by bioclimatic methods.

DETERMINATION OF THE SUM OF 12-HOUR UNITS

The relative sums of 12-hour units of day and night time for the variable periods between the equinoxes and solstices for representative latitude are determined by appendix table 15 north and south. The conception and development of this principle and method was based on (1) information supplied to the writer in 1923 by the United States Naval Observatory at Washington on the total hours between sunrise and sunset for given latitudes; (2) computation for additional latitudes from table 4 of Local Mean Time of Sunrise and Sunset in the United States Coast and Geodetic Survey Tide Tables for 1923; and (3) further determination of sums for intervening latitudes by the chart method (fig. 29).

LAW OF DAY AND NIGHT TIME

From the foregoing outline of cause, effects, constants, and variables, it will be recognized that there is such order and system in the length of day and night time relative to terrestrial latitude and celestial longitude and the two major motions of the earth as to represent natural law. This law is directly related to the proposed astronomical, astroterrestrial, and terrestrial laws of the seasons in that (*a*) the progressively shorter astroterrestrial season constants poleward from near the tropical circles by distance in degrees of latitude, relative to the astronomic periods of the year, are characterized by progressively longer or shorter periods of day and night time; (*b*) the variable terrestrial seasons relative to distance in latitude and altitude between the equator and the poles are modifications of the astroterrestrial constants; and (*c*) the exceedingly variable length of each of the distinctive terrestrial seasons in the same latitude within the zone of the four seasons have the same average or sum constant of daytime for each degree of latitude in each of the astronomic periods of the year.

PRINCIPLES OF THE LAW

The essential principles of the law of day and night time as to causes are the same as those relative to time and the motions of the earth and the laws of the seasons in that the increase or decrease of the sum constants of day and night time with distance in latitude between the poles is relative to the revolution of the earth in its orbit and the inclination of its axis during the four astronomic periods of each calendar year.

Thus the progressive movement of time in days, dates, periods, and seasons of the year with the two major motions of the earth have their corresponding progressive increase and decrease of the sum constants of day and night time both as related to the astronomic seasons in all latitudes from pole to pole and to the astroterrestrial season in specific latitudes of the three zones of the seasons, I, arctic or winter zone; II, intermediate or zone of the four seasons (spring, summer, autumn, and winter); and III, tropical or summer zone.

The sum constants of 12-hour units of daytime for given latitudes between the Equator and the poles, or between the poles, is relative to the astronomic seasons of the year, because the increase and decrease occur in, and are determined for, these constant periods between the date constants of the equinoxes and solstices which are equal from pole to pole. Thus just as the dates and periods of the variable astroterrestrial seasons are constants for all terrestrial latitudes, the sums of day and night time are constants for given latitudes which are modifying elements of the terrestrial seasons regardless of altitude or other physical features of the surface of the earth.

In figure 29 are dates at intervals of 4 days, more or less, for each 4° of the orbit; the vertical degrees from latitude 90° north to 90° south; the *EC* and *SC* colures; the day time sum constant lines *a*, *d*, *f*, and *g* (*b*, *c*, *e*, and *h* night time) and the *C1*, *C4*, *C6*, and *C7* day and *C2*, *C3*, *C5*, and *C8* night intervals. The day and night intervals of periods 1 and 2 extend from their sum constant lines (as *a* day and *b* night for period 1) to the June colure (*SC*), and those for periods 3 and 4 to the December colure. Between latitudes 15° and 23°30′ north and latitudes 5° and 15° north the scales give the units of day and night.

THE SEASONS OF THE YEAR

GENERAL PRINCIPLES

ASTRONOMIC SEASONS

The primary constant effects of astronomic causes are the astronomic seasons as defined by the dates of the equinoxes and solstices for the beginning of each of the four periods of the astronomic year: as period 1 of 93 days beginning on the average at March 20; period 2 of 93 days, beginning June 21; period 3 of 90 days, beginning September 22; and period 4 of 89 days, beginning December 21. Each period is constant for all terrestrial latitudes and is in no way modified by any physical features of the surface of the earth.

ASTROTERRESTRIAL SEASONS

The primary variable effects of astroterrestrial cause are the seasons of varying lengths between the equatorial and polar regions, designated as astroterrestrial seasons, coming in major II season zones of the Northern and Southern Hemispheres and between polar and alpine zone I of perpetual winter temperature and equatorial zone III of perpetual summer temperature.

These astroterrestrial seasons are related to sea-level latitude alone around the earth. Although they are modifications of the astronomic seasons, they are not modified by the unequal distribution of land and water or by the elevation of land above the sea. They are characterized (1) by definite period constants as in appendix table 16; (2) by a marked difference in the relative length or sums of daytime and nighttime, which difference increases from near the Equator to the poles; and (3) by constant ranges in sea-level temperature, as represented by tables and charts of thermal constants.

TERRESTRIAL SEASONS

The terrestrial seasons of zone II of the four seasons are the effects of major astronomic and astroterrestrial causes, as profoundly modified by major and minor terrestrial elements, including the unequal distribution of land and water, elevation of land above the sea, general topographic features, etc. Thus within zone II there is a wide variation in the dates of beginning and ending and length of each of the four seasons in the same latitude across a continent, as controlled by elevation of the land alone, ranging from perpetual

winter of zone I at sea level poleward to above snow line on the higher mountains of zone III.

CLASSIFICATION OF THE SEASONS OF THE YEAR

ORDER OF THE SEASONS

The order of the seasons of the astronomic and calendar year includes three major and a number of minor divisions as characterized by (A) purely astronomic; (B) astroterrestrial; and (C) purely terrestrial elements of distinction, as follows:

MAJOR ORDERS

A. Astronomic season constants are characterized and limited by the equinoxes and solstices and are unmodified by terrestrial latitude.

B. Astroterrestrial season constants are characterized and limited by latitude and temperature to represent modifications of the astronomic seasons by the inclination of the earth's axis. They vary widely in length between low and high latitudes but are unmodified by altitude or other physical features of the surface of the earth.

C. Terrestrial seasons are variable modifications of the astroterrestrial seasons and are characterized by ranges in average temperature, by dates and periods of seasonal phenomena, by distance in latitude north and south of the Equator, by longitude east and west across the continents, and by altitude above the sea.

Divisions of Major A (Astronomic Seasons)

The date and period constants of the astronomic year (of 365+ days) are:

1. From March 20 to June 21, 93 days.
2. From June 21 to September 22, 93 days.
3. From September 22 to December 21, 90 days.
4. From December 21 to March 20, 89 days.

Divisions of Major B (Astroterrestrial Seasons)

The zonal constants of the astroterrestrial seasons are:

Zone I, arctic, of perpetual winter poleward from the polar circles.

Zone II of the four seasons between latitude 27 north and south and the polar circles (1 spring, 2 summer, 3 autumn, and 4 winter north, and 3 spring, 4 summer, 1 autumn, and 2 winter south).

Zone III, of perpetual summer between latitudes 27 north and south.

All three of these zones are relative to a sea-level plane and are modified only by distance in latitude under the influence of the inclination of the earth's axis.

Divisions of Major C

The zones of major C are the same as those of major B but are *variable* in that they are subject to profound modification.

Zone I, polar and alpine, has a short cool period in its lower latitude and altitude limits and one long cold or perpetual winter period to the poles, and above snowline on plateaus and mountains above zones II and III.

Zone II has the four distinctive seasons of division B, but each is subject to modification by continental, regional, and local physical features of land and water.

Zone III has three perpetual seasons as modified by altitude and characterized by temperature: (1) perpetual warm summer at lower altitudes; (2) perpetual cool or intermediate season at intermediate altitudes; and (3) perpetual cold season at higher altitudes.

Each of these is modified more or less between its latitude limits, longitude east and west, and especially by altitude above the level of the sea.

TYPES OF SEASONS OF MAJOR C

There are many and varied types of the major and minor divisions of the season zones of order C, as characterized by their length (between the dates of beginning and ending in zones II) and by their variation from the astroterrestrial requirement constants for latitude, isophane, or altitude. They are also characterized by wet and dry; marine or coastal; mountain, continental, or interior; and by regional and local types, which are discussed below under types of seasons and zones.

KINDS OF SEASONS

The term "season", in addition to its application to the three major orders and their divisions as related to the astronomic calendar year, is also applied to characterizing climatic elements and to many and varied subjects relating to seasonal phenomena, practice, etc. Among those are the following:

(*a*) Thermal seasons, based on averages and ranges of temperature.

(*b*) Frostless seasons, based on dates of the latest killing frost in spring and earliest in autumn.

(*c*) Phenological seasons, based on dates and periods of seasonal phenomena of plants and animals and on farm and garden, as well as other periodic, practices of man.

(*d*) Geographic seasons, based on the distribution, range, and limits of the terrestrial seasons on the continents and their major types as related to geographic regions and zones as shown on maps.

(*e*) Geologic seasons as indicated by the remains of plants and animals which were characteristic of different geological periods and serve as evidence of profound differences in climates and seasons from those prevailing in the same parts of the world at present.

CONSTANTS AND VARIABLES

There are certain constant and variable elements of cause and effect relative to the three major orders of the seasons of the year and their minor divisions which form the basis for a comprehensive study and interpretation of bioclimatic problems.

Major and Minor Causation Constants

The major causation constants which are fundamental in the control of the seasons of the calendar year are (1) the sun and (2) the revolution of the earth and the inclination of its axis as measured (*a*) by unit constants of mean solar time on the clock and (*b*) by days and dates of the calendar relative to distance in celestial longitude and terrestrial latitude.

The minor causation constants which serve to modify the effects of major causes of the terrestrial seasons are the physiographic features of the surface of the earth such as the interrelations of land and water and the elevation of the land above the sea.

Major and Minor Variables

The major variables of the astroterrestrial seasons are those in which their relative lengths are governed by the inclination of the earth's axis and characterized by

ranges in the sum constants of daytime between the dates of the equinoxes. The relative sums of daytime varying with distance in latitude are designated as constants in that the decrease in length of the warm season poleward and the cold season equatorward are unmodified by terrestrial influences.

The major variables of the terrestrial seasons as compared with those of the astroterrestrial seasons, are those in which the relative length and period constants of the latter are modified by physical features of the surface of the earth and therefore are true variables by which in comparison with the period constants for given latitudes, the relative intensity of the modifying effects of terrestrial influences are measured and interpreted.

Major and Minor Constant and Variable Effects

In order A the major constant effects of the major causes are the four astronomic seasons as defined by the periods in days between the dates of the equinoxes and solstices, each of which is constant in length of time in all terrestrial latitudes from pole to pole.

In order B the major effects are in the modified length of the season constants of order A; in the three major zonal constants, which on a sea-level basis are limited to definite ranges of latitude; and the season constants to definite parallels around the world, as in zone I of perpetual winter, zone II of the four seasons, and zone III of perpetual summer.

In order C the major constant effects are the same as in order B, but the minor effects of terrestrial influences along any given parallel of latitude across the land and water are exceedingly variable in the ranges and limits of the three major zones, and especially in the dates of the beginning and ending and the length of the seasons in zone II.

Thus the actual terrestrial seasons as observed in any season zone on any continent, or in any region or place, will be found to vary from the date and period constants of order B. In fact the terrestrial seasons as related to latitude between the equator and the poles are so variable in length, as characterized by temperature, dates, and periods of seasonal phenomena, etc., that *there is evidently no place on the face of the earth where the actual dates of the beginning and ending of spring, summer, autumn, and winter agree exactly with the dates and length of the astronomic seasons of order A.* Furthermore, there is evidently no place in any latitude in zone II of order C, even on a sea-level basis, where the four seasons agree exactly with the date and period constants of order B for the same latitude; yet the date and period constants as given in table 16 serve as reliable indices to the interpretation and study of the variable terrestrial seasons.

APPLICATION IN BIOCLIMATICS

The application of the principles, classification, and general information relative to the three orders of the seasons of the year, is in the study, comparison, and interpretation of the seasons as related to (*a*) the major and minor bioclimatic zones; (*b*) the climatic regions; and (*c*) more specifically to representative geographic positions.

Methods

The methods to attain the desired results in the different branches of the natural sciences involve the fundamental bioclimatic principles of the constant and variable, in which the variation of the variable from its constant—in terms of time, temperature, or distance—is a measure of the extent to which the constant is modified by major and minor causes and factors (the causation-factor complex) and permits one to interpret in the same terms the relative intensity of such modifying influences.

Thus the astroterrestrial constants in time, temperature, and distance serve as the fundamental basis of reference to determine the extent of the variation of any record from its corresponding constant. And *it is from such variations,* as determined for representative positions of a local or general region (individually, or collectively as averages) *that the key is found for interpreting the character and length of the terrestrial seasons that may be expected to prevail at any given geographic position within the area represented.*

LAWS OF THE SEASONS

From the foregoing discussion, it will be recognized that there is such order and coordination of principles as to represent natural law and to justify further discussion of these principles under the laws of the seasons as follows:

A. The *astronomic seasons* represent the constant effect of constant astronomic causes and are characterized by the unmodified length of the periods in days between the dates of the equinoxes and solstices.

B. The *astroterrestrial seasons* represent the constant effect of the same major causes but they are modified by the inclination of the earth's axis as related to the surface of the earth and are characterized by (*a*) range and limits in length between given parallels of latitude, (*b*) ranges in sum constants of daytime and nighttime of the four periods of the astronomic year, and (*c*) by ranges in constants of average annual temperature.

C. The *terrestrial seasons* represent the variable effect of astronomic and terrestrial causes as revealed in the variations from the requirement constants of B and are caused by the varying physical features of the surface of the earth.

DESIGNATION AND APPLICATION OF ASTRONOMIC SEASONS

Since the original designations of spring, summer, autumn, and winter as specific periods of the year, beginning on the dates of the equinoxes and solstices, were based on astronomic observations and on general agricultural experience within the Mediterranean region, they apply only in a general way to certain latitudes and positions of that region and its peculiar type of climate. Since as a purely astronomical conception the four astronomic seasons are thus of little or no practical importance as applied to tropical and arctic latitudes, they are to be considered in bioclimatics simply as periods of the astronomic year between the March equinox of one and that of the next calendar year.

COMPARISON OF PRINCIPLES OF ASTRONOMIC AND ASTROTERRESTRIAL MOVEMENTS OF TIME

A comparison of the principles of movements in time with distance in degrees of latitude and degrees of the orbit relative to the astronomic and astroterrestrial laws of the seasons is best shown by the chart method.

Figure 30 shows in comparison the requirement lines of movement in time with distance in degrees of terrestrial latitude and celestial longitude of the astronomic law, with the additon of those of the astroterrestrial law *d1, d4, d1* north, and *d4, d1, d4* south. The principles and elements of this chart are the same as in figure 28 *B*, in which the astronomic movements by latitude are represented by date constants as given in columns *a1*, *b1*, and *c1* of appendix table 13, and *a2*, *b2*, and *c2* of table 14.

The date lines *d1N* and *d4N* represent the astroterrestrial movement by date constants between latitudes 27° and 66.46° north; *d1N* from orbit degree 315, February 3, in latitude 27° to 66.46° north in orbit degree 135, on August 6; *d4N* from August 6 in return to February 3 in latitude 27° north and orbit degree 315; then *d1N* back to August 6; while *d4S* and *d1S* represent the same movement south from February 3 of the first year and *d4S* to August 6 of the second year. Thus one complete revolution of the earth in its obrit of 360° in 365+ days of time is represented by lines *d1* and *d4* north, *d4* and *d1* south from February 3, or 549 days to August 6 of the second calendar year.

In further explanation, I, II, and III give the latitude range and limits of the season zone constants north and south. The horizontal lines and spaces as numbered to the right give: 1, the degrees of the orbit at intervals of 45° from 270 on the December 21 solstitial colure (*SC*) of one calendar year to the same degree and position of the second year and on to 135 on August 6 of the third year; 2, *EC* equinoctial and *SC* solstitial colures; 3, the North Pole; 4, the Arctic Circle and equatorward limit of season zone I and polar limit of season zone II north; 5, the equatorward limit of zone II and poleward limit of zone III north in latitude 27°; 6, Tropic of Cancer; 6a, the Equator with periods in days between *EC* and *SC*, and 46 days between the June solstice and August 6; 7, Tropic of Capricorn; 8, latitude 27° south and south-poleward limit zone III and equatorward limit of zone II south; 9, Antarctic Circle and poleward limit of zone II and equatorward limit of zone I south; 10, South Pole; 11, year-dates corresponding with the degrees of the orbit in the orbital movement, and for the latitudes intersected by the date lines *a*, *b*, *c*, and *d*, with their suffixes of arabic numerals; and 12, the corresponding month dates.

RATES OF MOVEMENT IN TIME RELATED TO LATITUDE

The rates of movement in the astroterrestrial seasons as related to latitude apply only to zone II (north and south), and since the seasons of the northern zone come in different months of the year from those of the southern zone, it is necessary to compute and apply the rates separately.

Thus, since different periods of days are represented in the north zone between February 3 of one year and February 3 of the next year from those of the southern zone between August 6 of one year and August 6 of the next year, the rates of movement between given latitudes and dates in the two zones are different, as shown in examples 38 and 39.

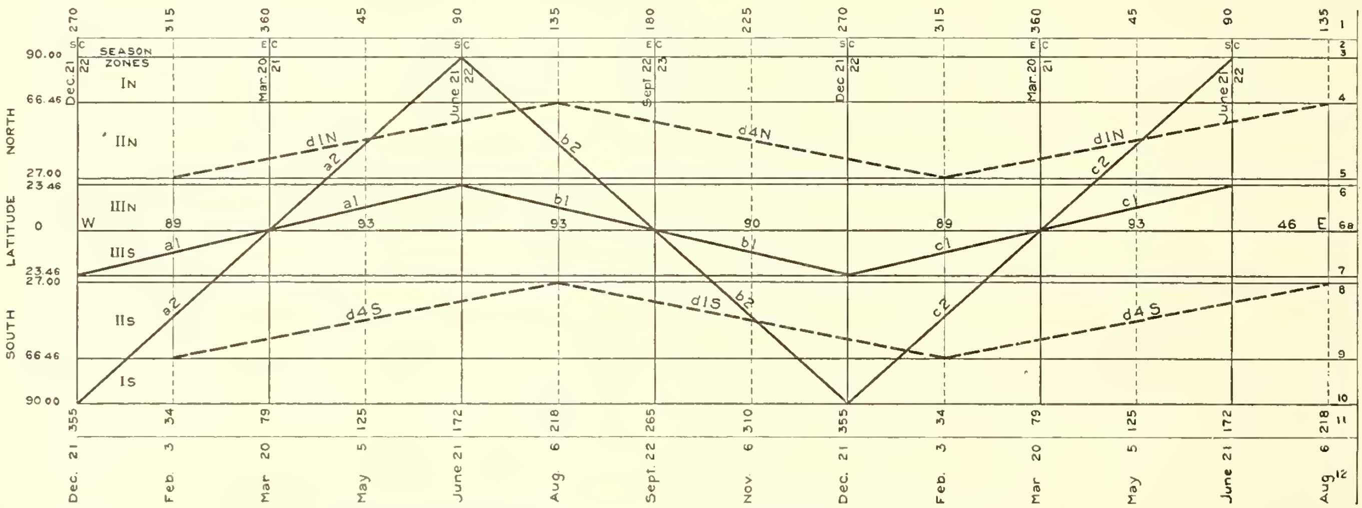

FIGURE 30.—Comparison of principles of the astronomic and astroterrestrial seasons.

EXAMPLE 38.—*Astroterrestrial season zone II north, rates of movement in time to distance in degrees of latitude between 27° and 66.46° for the beginning of spring and winter*

Date lines	North latitude	Date	Period	Distance	Rate
			Days	*Degrees*	*Days*
d1N	27.00	Feb. 3			
d1N	36.75	Mar. 20	44.519	9.75	4.5660+
d1N	56.50	June 21	93.078	19.75	4.7128+
d1N	66.46	Aug. 6	46.539	9.96	4.6725+
d4N	56.50	Sept. 22	46.539	9.96	4.6725+
d4N	36.75	Dec. 21	90.048	19.75	4.5593+
d4N	27.00	Feb. 3	44.519	9.75	4.5660+
		Year	365.242	78.92	[1] 4.6280+

[1] Average.

In example 38, latitudes 27° to 66.46° north and the corresponding dates for the beginning of spring (line *d1N*) and the beginning of winter (line *d4N*) in figures 30 and 31 is based on an extensive study of the sea-level monthly mean isotherms of the Northern and Southern Hemispheres, which indicated that on a general sea-level average, spring of the northern zone II as characterized by temperature begins about February 3 in about latitude 27°, and that relative to the inclination of the earth's axis it is progressively later with higher latitudes to about August 6 at or near the Arctic Circle, where the characterizing spring temperature of zone II merges into the cool-to-cold temperature of zone I; and that in the return equatorward movement the change to winter temperature in zone II is progressively later from August 6 at or near the Arctic Circle to February 3 in about latitude 27°,

where the mild winter temperature merges into that of the summer temperature of zone III.

On this basis it is assumed that under the requirements of astroterrestrial law the warm (spring, summer, and autumn) and cold (winter) periods of zone II—under constant causes and effects relative to sea-level latitude—are represented by constant dates and periods in days, and that the rate of movement between the given latitudes for the progressive poleward movement and return equatorward movement would be as given in this example, in which the period in days is divided by the distance in degrees to find the rate per degree.

In this and example 39, decimals to the third place are utilized for periods in days, and the rates in days are carried to the fourth place with plus (+) indicating that they may be extended. The object of these decimals is to make them available for any decimal extension toward precision in fractions of a day in the computation of date and period constants of a table, although it is not necessary or practical in bioclimatics as related to seasons or seasonal phenomena to utilize time units of less than the 24-hour day from one calendar date to the same time on the next succeeding date.

Application of the rates in this example is in computing date constants to represent the movement in calendar dates by degrees of latitude north for the beginning of spring from February 3 in latitude 27° to August 6 in latitude 66.46°, and for the beginning of winter from August 6 to February 3, as given for each degree of latitude in appendix table 16 north, in which the decimals utilized in the computation are omitted, as there explained.

VERIFICATION BY THE CHART METHOD

Before inclusion in the table the computed dates by the given rates were verified by the chart method. This is on the principle that the intersection of a given event date line of any given angle (as for lines *a1*, *a2*, *d1*, etc., of figs. 30 and 31) with a latitude line and a given date and orbital degree line (represented by the longitudinal lines and spaces) must have the same date for a degree of latitude as for a corresponding degree of the orbit.

EXAMPLE 39.—*Astroterrestrial season zone II south, rates of movement in time to distance in degrees of latitude between 27° and 66.46° for the beginning of spring and winter*

Date lines	South latitude	Date	Period	Distance	Rate
			Days	*Degrees*	*Days*
d1S	27.00	Aug. 6			
d1S	36.75	Sept. 22	46.539	9.75	4.7732+
d1S	56.50	Dec. 21	90.048	19.75	4.5593+
d1S	66.46	Feb. 3	44.519	9.96	4.4697+
d4S	56.50	Mar. 20	44.519	9.96	4.4697+
d4S	36.75	June 21	93.078	19.75	4.7128+
d4S	27.00	Aug. 6	46.539	9.75	4.7732+
		Year	365.242	78.92	[1] 4.6280+

[1] Average.

In addition to the explanation of example 38 which applies to example 39, spring in the southern zone II begins in latitude 27° south on August 6 and is progressively later along date line *d1S* to February 3 in latitude 66.46°, where winter begins, and is progressively later along date line *d4S* to August 6 in latitude 27°, with the period in days, the distance in degrees of latitude, and the rates in days as given. These rates are applied in the computation of appendix table 16, south, which includes verification by the chart method.

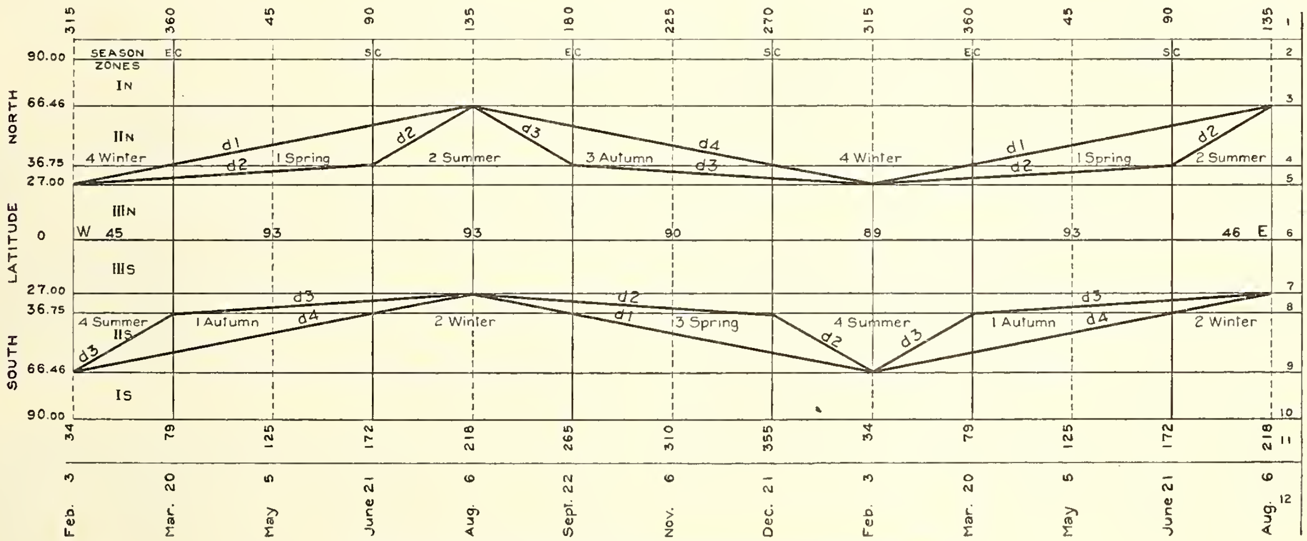

FIGURE 31.—Astroterrestrial zone II of the four seasons, north and south.

SUMMER AND AUTUMN DATES

It will be noted that the rates given in examples 38 and 39 and the corresponding date constants of table 16 are for the beginning of spring and winter north and south, but do not give the rates for the beginning of summer and autumn. These date constants (as in table 16) for the beginning of northern and southern summer and autumn are determined by the chart method, as by the lines of movement *d2* and *d3*, for both northern and southern latitudes (fig. 31).

The object of figure 31 is to show the essential principles of the law of the astroterrestrial seasons with reference to the three north and south zones of the seasons, and with special reference to zone II of the four distinctive seasons. The basic elements of this chart are the same as those of figure 30.

The oblique or angular date lines represent two movements in time, one with the revolution of the earth from west to east at the rate of about 1 day to 1° of its orbit, the other north and south with the inclination of the axis at rates per degree of latitude varying with the distance and the angle of the given date lines, but always with the date for any angular date line corresponding with that of the orbital date line where it crosses a given latitude line; for example, March 20 on orbit degree 360 is the same for any angular or latitude line where it crosses the 360° line. Thus the dates for any angular distance in latitude may be determined from the chart by the dates for the orbit (or vice versa).

In this chart the distance in terrestrial latitude is from pole to pole, while the distance in celestial longitude or degrees of the orbit is from 315° to 360°, 0° to 360°, and 0° to 135°, a total of 540°, including one complete and about one-half circuit of the orbit in 549 days of time from February 3 midnight of one calendar year to the same date and on to August 6 midnight of the next calendar year.

In the vertical column to the right 1 gives the orbital degrees; 2, the North Pole, and *EC* the equinoctial and *SC* solstitial colures; 3, the Arctic Circle and poleward limit of northern zone II; 4, latitude 36.75° north in which the dates and periods for the astroterrestrial seasons agree with the astronomical dates and periods; 5, latitude 27° north and equatorward limit of northern zone II; 6, the Equator and periods in days between *EC* and *SC;* 7, latitude 27° south and equatorward limit of the southern zone II; 8, latitude 36.75° south, with the dates and periods agreeing with those of the astronomic but the designations of the seasons reversed; 9, Antarctic Circle and poleward limit of southern zone II; 10, South Pole; 11, the year-date constants; and 12, the corresponding month date constants for the given orbital degrees and intersecting latitude and event date lines. *Season zones* gives major I polar of perpetual winter, II of the four distinctive seasons, and III of perpeutal summer.

One of the significant features of this chart is in showing the relations between the astroterrestrial seasons of zones II north and south in which the zones and angular date lines represent the requirements of the astroterrestrial law, as related to sea-level latitude, to serve as a coordinate basis of reference in the study and interpretation of the variable terrestrial seasons and seasonal phenomena in general.

In zone II north date line *d1* represents the ending of winter and beginning of spring, *d2* the ending of spring and beginning of summer, etc.; while in zone II south, *d3* represents the ending of the first summer and the beginning of autumn, etc.

Thus, while there are in succession (4) winter, (1) spring, (2) summer, and (3) autumn north, there are in the same sequence with approximately the same dates (4) summer, (1) autumn, (2) winter, and (3) spring south. (See table 16 for date and period constants at intervals of 1° of latitude and fig. 32 for more detailed explanation.)

The principle and elements of figure 32 of northern zone II of the four astroterrestrial season constants are the same as in figure 31, but on a much larger scale, with the latitudes from 27° to 66.50° given at intervals of 1°, and the degrees of the orbit at intervals of 4, with corresponding year-dates at intervals of 4 days (more or less, to provide for the fraction of a day in the average rate).

The numbers to the right for the spaces and lines give: 1, the degrees of the orbit, *EC* the equinoctial and *SC* solstitial colures, *MW* for midwinter and *MS* for midsummer; 2, the degrees of the orbit at intervals of four; 3, the length of winter in and above latitude 66.50°; 4, latitude 56.50° in which the period constants (31 days) of spring, summer, and autumn are equal, with a total of 93 days as between the March equinox and June solstice and the June solstice and September equinox; 5, latitude 36.75° with the months below, in which the astroterrestrial season date and period constants are the same as the astronomic seasons; 6, the year-dates from 34 (Feb. 3) of one calendar year to the same date of the next year; 7, specific dates for *d1* and *d4;* and 8, for *d2* and *d3* lines.

The lengths of period (or season) constants in days are given for representative latitudes between the beginning and ending date lines of each, as between *d1* and *d2*, *d2* and *d3*, *d3* and *d4*, as given in table 16, north, with *d1* to *d4* representing the warm period of the year and the total length of this major period on line *d4* and the major cold period represented in the *MW* line to the right from the beginning of winter *d4* to the beginning of spring *d1*.

It will be noted that between lines *d1* and *d2* spring increases in length poleward from latitude 27° to 36.75° and between lines *d3* and *d4* autumn decreases equatorward from 36.75° to 27°; while between lines *d2* and *d3* summer decreases rapidly from latitude 27° to 36.75°. Also seasons 1, 2, and 3 decrease in length poleward from latitude 36.75° to 0 in latitude 66.50°, while winter decreases in length equatorward from the Arctic Circle to latitude 27°. All of this, including the dates of beginning and ending of the seasons by the date lines, represents the requirement constants of astroterrestrial law in zone II north.

It is assumed, from the results of a study of average temperature on given parallels around the globe, that latitude 27° north and south as characterized by its normal annual temperature represents the colimit constant of season zones II and III north and south of the Equator, and that the Arctic and Antarctic Circles, as characterized by their normal temperature represent the colimit constants of zones I and II north and south.

It has been found by repeated tests that this conception of principles and requirement constants of the *law of astroterrestrial seasons*, as represented by table 16 and figure 31, agree closely enough with the general average seasonal periods around the world at sea level to give a reliable basis for the study and interpretation of the *law of terrestrial seasons*, as applied to any geographic position on the continental areas of both hemispheres.

OUTSTANDING AND SIGNIFICANT FEATURES OF THE TABLES AND CHARTS OF DATE AND PERIOD CONSTANTS

Some of the significant features of the appendix tables of date and period constants and the charts are (1) the relative lengths of spring, summer, autumn, and winter period constants in given latitudes; and (2) the relations of the dates and periods of the astroterrestrial seasons to those of the astronomic, which agree only in latitude 36.75° for the beginning of the seasons. And in latitude 56.50° north and south the total length of the spring, summer, and autumn is equal to the summer period in latitude 36.75°.

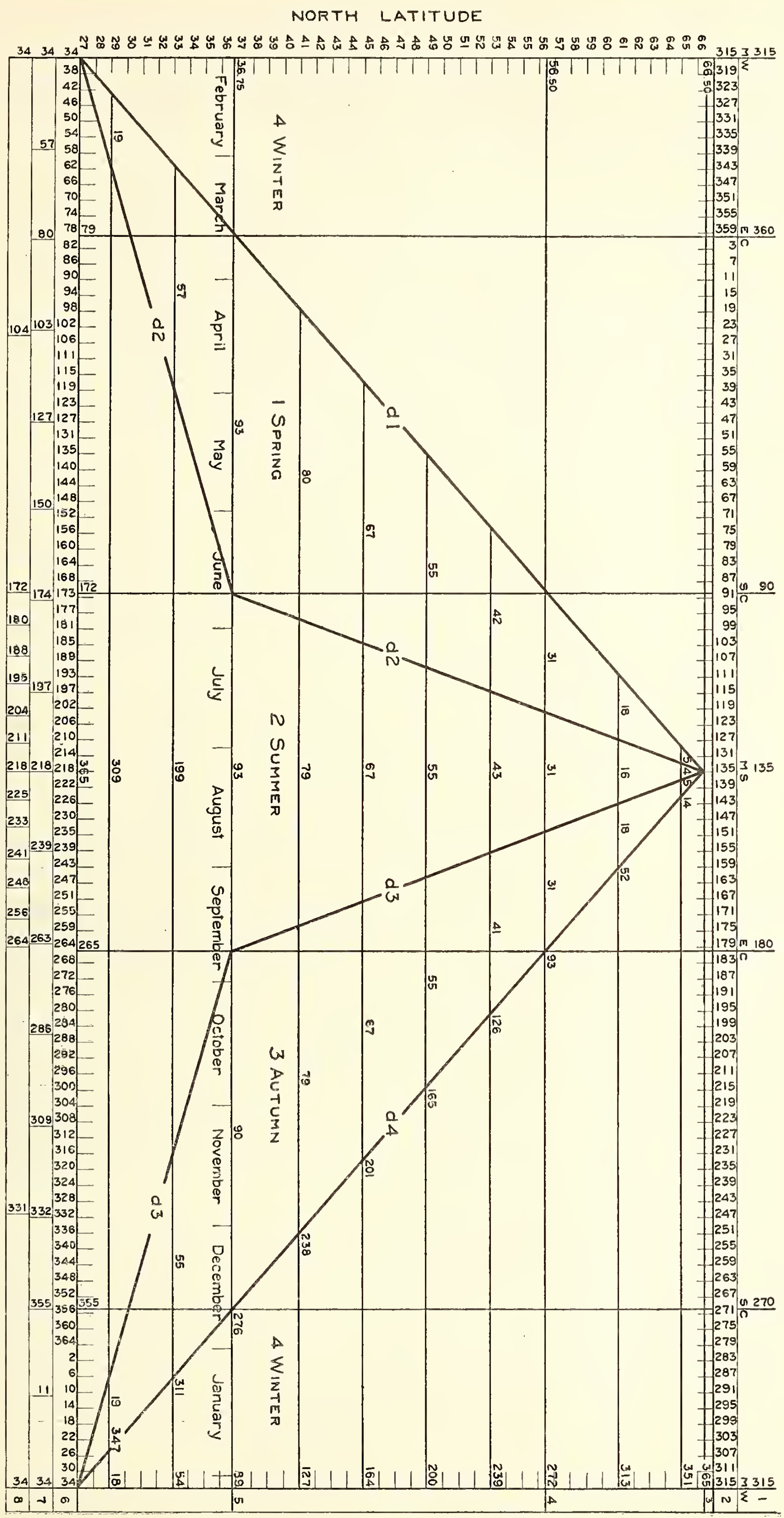

FIGURE 32.—Astroterrestrial zone II of the four seasons, north.

DIFFERENCE BETWEEN ASTRONOMIC AND ASTROTERRESTRIAL SEASONS

The astronomic seasons (spring, summer, autumn, and winter) as specific terms are limited by the celestial colures and apply alike to all terrestrial latitudes, while the astroterrestrial seasons apply to an assumed level plane of the earth's surface as periods of time of widely varying lengths in different latitudes between the Equator and the poles.

RELATIONS BETWEEN ASTROTERRESTRIAL AND TERRESTRIAL SEASONS

The astroterrestrial seasons are assumed constants relative to latitude alone and are unmodified by elevation of the land or other physiographic features of the earth's surface, while the terrestrial seasons represent variable effects of the influence of physiographic features. Furthermore, the astroterrestrial seasons represent an ideal system as related to the latitudes of a level surface, while the terrestrial seasons are this ideal modified by terrestrial influences. Thus the former is represented by zonal, date, and period constants as requirements of its law, while the latter is represented by corresponding zonal, date, and period variables as represented by observed and recorded data, with the variations of the records from the constants serving as a measure of the relative intensity of the modifying influences.

ASTROTERRESTRIAL AND TERRESTRIAL SEASONS OF ZONE II

The relations between the (*a*) astroterrestrial constants and (*b*) the terrestrial variables of zone II north and south are of special significance because it is in this zone that the four distinctive seasons of the year occur, and because the constants in (*a*) serve as indices to the study and interpretation of the variables in (*b*).

A comparison (example 40) based on the charts and tables will bring out some of the essential features of the principles of the requirement constants of astronomic and astroterrestrial laws of the seasons to be considered in connection with those of the law of the terrestrial seasons.

EXAMPLE 40.—*Comparison of astronomical and astroterrestrial season period constants for representative sea-level latitudes of the season zones*

Season zones	Latitude	1 spring		2 summer		3 autumn		4 winter	
		AP	*BP*	*AP*	*BP*	*AP*	*BP*	*AP*	*BP*
I N	90.00	93	0	93	0	90	0	89	365
	66.50	93	0	93	0	90	0	89	365
II N	56.50	93	31	93	31	90	31	89	272
	36.75	93	93	93	93	90	90	89	89
	27.00	93	0	93	365	90	0	89	0
III N	23.50	93	0	93	365	90	0	89	0
	0.00	93	0	93	365	90	0	89	0
III S	23.50	93	0	93	0	90	0	89	365
II S	27.00	93	0	93	0	90	0	89	365
	36.75	93	93	93	93	90	90	89	89
	56.50	93	30	93	276	90	29	89	30
I S	66.50	93	0	93	365	90	0	89	0
	90.00	93	0	93	365	90	0	89	0
		1 (spring)	1 autumn	2 (summer)	2 winter	3 (autumn)	3 spring	4 (winter)	4 summer

RELATIONS BETWEEN ASTRONOMIC AND ASTROTERRESTRIAL SEASONS

Example 40 shows the relations between the sea-level astronomic and astroterrestrial seasonal periods of the year. *Latitude* gives representative and limiting latitudes of the season zones north and south of the equator; *AP* the astronomical period constants in days of (1) spring, (2) summer, (3) autumn, and (4) winter, which in each case is the same for all latitudes north and south (tables 13 and 14); *BP* gives the astroterrestrial period constants (table 16 and figs. 31 and 32) for the seasons under the same numbers and names for the north on the upper line, but with the names reversed for the same numbers south on the lower line.

This comparison brings out especially clearly (1) that there is a marked difference between the length of the *A* and *B* seasons in different zones, and (2) that the only latitude in which the length of the seasons of *A* and *B* agree is in 36.75° north and south.

Another comparison of special interest is in the period constants of the astroterrestrial seasons under the same designation in zone II north and south, as shown in example 41.

Example 41 gives a comparison of the period constants of table 16, north and south, in the corresponding movements of the astroterrestrial seasons in season zone II north and south. *Season zones* gives the colimit

EXAMPLE 41.—*Comparison of period constants of the astroterrestrial seasons in zone II north and south for representative latitudes*

Season zones	Latitude N. and S.	1 spring north	3 spring south	2 summer north	4 summer south	3 autumn north	1 autumn south	1 + 2 + 3 north	3 + 4 + 1 south	4 winter north	2 winter south
		p	*p*	*p*	*p*	*p*	*p*	*p*	*p*	*p*	*p*
I	66.50	0	0	0	0	0	0	0	0	365	365
II	60.00	20	20	20	20	20	20	60	60	305	305
	56.50	31	29	31	30	31	30	93	89	272	276
	54.00	39	38	40	38	39	38	118	114	247	251
	51.00	48	46	48	47	48	47	144	140	221	225
	48.00	58	56	58	56	57	57	173	169	192	196
	43.00	75	71	72	70	73	74	220	215	145	150
	40.00	83	81	82	79	82	83	247	243	118	122
	36.75	93	90	93	89	90	93	276	272	89	93
	34.00	66	66	171	166	64	67	301	299	64	66
	30.00	28	28	282	279	27	29	337	336	28	29
II	27.00	0	0	365	365	0	0	365	365	0	0
III		0	0	365	365	0	0	365	365	0	0

of zones I and II in latitude 66.50° and of zones II and III in latitude 27, while *latitude N and S* gives representative latitudes north and south between 27 and 66.50°; 1 spring, 2 summer, 3 autumn, and 4 winter give *p* the season periods north, and 3 spring, 4 summer, 1 autumn, and 2 winter periods for the given latitudes south. Under 1+2+3 north and 3+4+1 south, is given the warm period of the year for the same latitudes.

It is of interest to note that in latitude 36.75° north and south the difference in length of the astroterrestrial seasons, 1 spring north and 3 spring south is (93−90) 3 days, while between 2 summer north and 4 summer south the difference is (93−89) 4 days, and that the sum of these differences is 7 days, which is the well-known difference between the period in which the vertical sun is north and south of the Equator during one complete revolution of the earth in its orbit. The same difference also prevails in that astronomic 1 (spring) 93 plus 2 (summer) 93 days equals 186 days north, and 3 (autumn) 90 plus 4 (winter) 89 days equals 179 days south; and 186 minus 179 gives a difference of 7 days.

Example 42.—*Comparison of the warm and cold period constants of the year in zone II north and south*

Periods	Latitude	66.50	60.00	56.50	54.00	51.00	48.00	43.00	40.00	36.75	34.00	30.00	27.00
Warm	North	0	60	93	118	144	173	220	247	276	301	337	365
	South	0	60	89	114	140	169	215	243	272	299	336	365
Cold	North	365	305	272	247	221	192	145	118	89	64	28	0
	South	365	305	276	251	225	196	150	122	93	66	29	0
NORTH COMPARED WITH SOUTH													
Warm	N. with S.	0	0	+4	+4	+4	+4	+5	+4	+4	+2	+1	0
Cold	N. with S.	0	0	−4	−4	−4	−4	−5	−4	−4	−2	−1	0

In example 42 the same latitudes of example 41 are given on the upper line with the corresponding period constants for the warm (spring, summer, and autumn) and cold (winter) periods of the year for each in zone II north and south. In the lower section under "north compared with south" is given the difference in days between the north and south warm and cold periods for the given latitudes. This shows in another way that the warm period north is longer and the cold period is shorter than they are south by the same number of days in each of the given latitudes.

THE ASTROTERRESTRIAL SEASON ZONES AS CHARACTERIZED BY THE SUM CONSTANTS OF DAYTIME

There is a close relation between the astroterrestrial season zonal constants and the sum constants of daytime in different latitudes, in that they represent effects of the same major causes in the revolution of the earth and the inclination of its axis.

Example 43.—*Astroterrestrial major season zones with limits and ranges in sum constants of daytime in 12-hour units*

Season zone	Latitude		1 spring		2 summer		3 autumn		1+2+3		4 winter		Year	
	Limits	Range	*dt*	*ra*	*dt*	*ra*	*dt*	*ra*	*tdt*	*ra*	*dt*	*ra*	*tdt*	*ra*
	90.00N		186		186		7		379		4		383	
I N.		23.50		43		42		45		40		47		7
	66.50		143		144		52		339		51		390	
II N.		39.50		41		42		31		52		31	.	21
	27.00		102		102		83		287		82		369	
		54.00		16		16		16		4		16		0
III									1+3+4					
	27.00S		86		86		99		283		98		369	
II S.		39.50		33		33		38		44		39		11
	66.50		53		53		137		327		137		380	
I S.		23.50		47		50		43		37		41		13
	90.00		6		3		180		364		178		367	
			1 autumn		2 winter		3 spring				4 summer			

Example 43 shows how the daytime sum constants of appendix table 15 serve to characterize the poleward and equatorward limits of the astroterrestrial season zones north and south and the ranges in sums for each zone and season for the range in degrees between the limiting latitudes. *Latitude* gives the latitude *limits* and *ranges* in degrees for each season zone I and II north and south, and III equatorial, with the *dt* daytime sums for each latitude limit and season in 12-hour units, and *ra* range in daytime units for each zone and season, and with *tdt* total daytime and *ra* range for the warm periods north (*1+2+3*) and south (*1+3+4*) and the year.

From this example it will be seen that each season and season zone north and south is characterized by a sum constant of daytime for its upper and lower latitude limits, and by a range in sums between its limits.

Example 44.—*Sums of daytime and length of the seasons for representative latitudes in astroterrestrial season zone II north and south*

Season zone	North latitude	1 spring		2 summer		3 autumn		1+2+3		4 winter		Year		*tdt*
		dt	*p*	*dt*	*p*	*dt*	*p*	*tdt*	*tp*	*dt*	*p*	*tdt*	*tp*	*diff*
II	66.50	143	0	144	0	52	0	339	0	51	365	390	365	+25
	64.00	134	7	136	8	58	7	328	22	56	343	384	365	19
	60.00	125	20	126	20	64	20	315	60	63	305	378	365	13
	57.00	121	30	121	29	68	30	310	89	66	276	376	365	11
	54.00	118	39	118	40	70	39	306	118	68	247	374	365	9
	51.00	115	48	115	48	72	48	302	144	71	221	373	365	8
	48.00	113	58	113	58	74	57	300	173	73	192	373	365	8
	43.00	110	75	110	72	77	73	297	220	76	145	373	365	8
	40.00	109	83	109	82	78	82	296	247	77	118	373	365	8
	37.00	106	92	106	92	80	91	292	275	79	90	371	365	6
	34.00	105	66	105	171	81	64	291	301	80	64	371	365	6
	30.00	103	28	103	282	82	27	288	337	81	28	369	365	4
	27.00	102	0	102	365	83	0	287	365	82	0	369	365	4

Season zone	South latitude	1 autumn		2 winter		3 spring		1+3+4		4 summer		Year		*tdt*
		dt	*p*	*dt*	*p*	*dt*	*p*	*tdt*	*tp*	*dt*	*p*	*tdt*	*tp*	*diff*
II	27.00	86	0	86	0	99	0	283	365	98	365	369	365	+4
	30.00	85	29	85	29	100	28	284	336	99	279	369	365	4
	34.00	83	67	83	66	102	66	286	299	101	166	369	365	4
	37.00	82	94	82	93	103	90	287	272	102	88	369	365	4
	40.00	81	83	81	122	104	81	288	243	103	79	369	365	4
	43.00	79	74	79	150	106	71	290	215	105	70	369	365	4
	48.00	76	57	76	196	109	56	293	169	108	56	369	365	4
	51.00	74	47	74	225	111	46	295	140	110	47	369	365	4
	54.00	71	38	72	251	114	38	298	114	113	38	370	365	5
	57.00	69	29	69	279	117	29	302	86	116	28	371	365	6
	60.00	66	20	65	305	121	20	307	60	120	20	372	365	7
	64.00	59	7	60	342	131	8	319	23	129	8	379	365	14
	66.50	53	0	53	365	137	0	327	0	137	0	380	365	15

Example 44 shows the relations between the sums of 12-hour units of daytime (*dt*) (appendix table 15) and the length of the astroterrestrial seasons (*p*) in 24-hour day units (appendix table 16) for given latitudes in season zone II north and south. Under *1+2+3* north and *1+3+4* south, *tdt* gives the total sum of 12-hour units of daytime and *tp* the total period in 24-hour units (day and night) for the three seasons, and under *year* the total sum of daytime in 12-hour units and total period in 24-hour units for the four seasons of the astronomic year, with the *tdt diff.* difference in units of 12 hours between the total sum of daytime and the total period in days in which the daytime for each latitude is (+) more than the total days, because there is on the average more daytime than nighttime.[23]

The significance of the length of daytime applies especially to the warmer part of the year because it is

[23] The 12-hour unit of daytime is comparable with the 24-hour unit because it represents the daytime half of the 24-hour unit.

in these seasons of plant and animal activities that the effective influence on their seasonal phenomena is manifested. It is true, however, that with artificial control of length of day under glass the influence of the short day is manifested, as has been shown so forcibly by Garner and Allard.

THE ASTROTERRESTRIAL SEASONS AND ZONES AS CHARACTERIZED BY AVERAGE TEMPERATURE

The modified thermal constants of appendix table 3 which serve to characterize the range and limits of the major and minor thermal and bioclimatic zones, as defined by isophanes at sea level or by latitude relative to the one hundredth meridian, are taken to characterize the range and limits of the astroterrestrial season zones as defined and limited by the given sea-level latitudes.

Example 45.—*Latitude range and limits of the astroterrestrial season zones as characterized by a, w, and c thermal mean constants of table 3*

Season zones	Latitude		Thermal constants and ranges					
	Limits	Range	*a*	*ar*	*w*	*wr*	*c*	*cr*
	90.00 N.		−6.25		29.00		−41.50	
I N		23.50		31.88		23.50		40.25
	66.50		25.63		52.50		−1.25	
II N		39.50		47.22		35.20		59.25
	27.00		72.85		87.70		58.00	
				16.15		2.30		30.00
III	.00	54.00	89.00		90.00		88.00	
				16.15		2.30		30.00
II S	27.00 S.		72.85		87.70		58.00	
		39.50		47.22		35.20		59.25
	66.50		25.63		52.50		−1.25	
I S		23.50		31.88		23.50		40.25
	90.00		−6.25		29.00		−41.50	

In example 45, *latitude* gives the latitude *limits* and *range* of the major season zones I and II north and south and of the equatorial zone III; *a* the annual mean constant, *w* the warmest month mean constant, and *c* the coldest month mean constant in degrees Fahrenheit of appendix table 3 for each of the given limiting latitudes; and *ar*, *wr*, and *cr* the range in *a*, *w*, and *c* temperatures for the latitude range of each zone. (See system of classification of bioclimatic zones, p. 96).

In adopting the thermal constants of table 3 to characterize the astroterrestrial season zones the one hundredth meridian of longitude is taken as the basis because on this meridian the numerical designations of the isophanes and latitudes are the same, and thus apply alike to the latitude range and limits of the season zones.

Example 46.—*Thermal constants for representative latitudes in astroterrestrial season zone II north and south*

North and South		Table 3			Isotherm	Table 4					Table 5
SZ	Latitude	*a*	*w*	*c*	50° 60°	*d*	*e*	*f*	*h*	*i*	*es*
	66.50	25.63	52.50	−1.25		36.80	64.20	80.52	−9.30	10.70	21.50
	60.00	33.75	59.00	8.50		44.92	70.70	88.58	0.45	20 45	47.00
	57.00	37.50	62.00	13.00		48.67	73.70	92.30	4.95	24.95	59.00
	51.00	45.00	68.00	22.00		56.17	79.70	99.50	13.95	33.95	99.00
II	48.00	48.75	71.00	26.50		59.92	82.70	102.50	18.45	38.45	123.00
	43.00	55.00	76.00	34.00		66.17	87.70	107.50	25.95	45.95	171.00
	40.00	58.70	78.90	38.50		69.86	90.60	110.40	30.45	50.45	201.00
	34.00	65.70	83.90	47.50		76.86	95.60	115.40	39.45	59.45	273.00
	30.00	69.85	86.20	53.50		81.01	97.90	117.70	45.45	65.45	321.00
	27.00	72.85	87.70	58.00		84.01	99.40	119.20	49.95	69.95	357.00

Example 46 gives for representative latitudes in astroterrestrial season zone II north and south, the *a*, *w*, and *c* constants from table 3; the constants of appendix table 4 under *d* the mean maximum temperature for the year, *e* the mean maximum for the warmest month, *f* the highest recorded temperature, *h* the mean minimum for the coldest month, and *i* the mean minimum for the year; and the constants of appendix table 5 under *es* the effective sum of the monthly means above 35° F. for isophanes at or above 60, 40° F. between isophanes 60 and 57, and 43° F. between 57 and 0 north and south; together with the latitude range and limit constants for the 50° and 60° monthly mean isotherms, with 50° between latitudes 66.50° and 34°, and isotherm 60° between latitudes 60° and 27°, as in example 69.

Example 47.—*Corresponding movements of the astroterrestrial seasons in zone II north and south by date and period constants of appendix table 16 for representative latitudes*

Season zone	North latitude	1 spring		2 summer		3 autumn		1+2 +3	4 winter	
		d1	*p*	*d2*	*p*	*d3*	*p*	*p*	*d4*	*p*
	66.50	218	0	218	0	218	0	0	218	365
	64.00	207	7	214	8	222	7	22	229	343
	60.00	188	20	208	20	228	20	60	248	305
	57.00	174	30	204	29	233	30	89	263	276
	54.00	159	39	198	40	238	39	118	277	247
	51.00	146	48	194	48	242	48	144	290	221
II	48.00	131	58	189	58	247	57	173	304	192
	43.00	107	75	182	72	254	73	220	327	145
	40.00	94	83	177	82	259	82	247	341	118
	37.00	80	92	172	92	264	91	275	355	90
	34.00	66	66	132	171	303	64	301	2	64
	30.00	48	28	76	282	358	27	337	20	28
	27.00	34	0	34	365	34	0	365	34	0

Season zone	South latitude	1 autumn		2 winter		3 spring		1+3 +4	4 summer	
		d3	*p*	*d4*	*p*	*d1*	*p*	*p*	*d2*	*p*
	27.00	218	0	218	0	218	0	365	218	365
	30.00	175	29	204	29	233	28	336	261	279
	34.00	118	67	185	66	251	66	299	317	166
	37.00	78	94	172	93	265	90	272	355	88
	40.00	74	83	157	122	279	81	243	360	79
	43.00	69	74	143	150	293	71	215	364	70
II	48.00	62	57	119	196	315	56	169	6	56
	51.00	57	47	104	225	329	46	140	10	47
	54.00	53	38	91	251	342	38	114	15	38
	57.00	48	29	77	279	356	29	86	20	28
	60.00	44	20	64	305	4	20	60	24	20
	64.00	38	7	45	342	22	8	23	30	8
	66.50	34	0	34	365	34	0	0	34	0

Example 47 gives the astroterrestrial date and period constants of table 16 for representative latitudes north and south in the corresponding movements of the seasons of zone II for comparison with the thermal constants in example 46 and appendix tables 3, 4, and 5 and with other record dates and periods for the same latitudes, such as those of late and early killing frosts (table 6), progress of the seasons by isotherms (example 69), and phenological indices (table 9 and example 48). The latitudes and season designations are the same as in example 44, while the symbols *d1*, *d2*, *d3*, and *d4* refer to the date columns in table 16 and corresponding date lines in figures 31 and 32. *p* gives the seasonal period constants in days between the dates for the beginning of each season, while *1+2+3* north and *1+3+4* south *p* gives the total warm period in each, and 4 north and 2 south give the cold periods of the year.

EXAMPLE 48.—*Phenological seasons, date, and period constants of table 9 for representative latitudes north*

BZ		Latitude isophane	SZ	1 spring		2 summer		3 autumn		1+2+3	4 winter		Yr.
Ma	*Mi*			*yd*	*p*	*yd*	*p*	*yd*	*p*	*p*	*yd*	*p*	*p*
I	2	75.00 N.		210	0	210	0	210	0	0	210	365	
		74.00		206	4	210	0	210	3	7	213	358	
	3	72.00	I	197	13	210	0	210	9	22	219	343	
		69.00		185	25	210	0	210	17	42	227	323	
		66.50		175	35	210	0	210	25	60	235	305	
	4	60.00		148	62	210	0	210	45	107	255	258	
II		58.50		142	68	210	0	210	49	117	259	248	
	1	57.00		135	69	204	12	216	49	130	265	235	
	2	51.00		111	68	179	61	240	49	178	289	187	365
	3	48.00		98	68	166	85	251	49	202	300	163	
		44.50		84	68	152	114	266	48	230	314	135	
	4	43.00	II	78	67	145	128	273	47	242	320	123	
	5	40.00		66	65	131	155	286	45	265	331	100	
	6	34.00		42	32	74	258	332	22	312	354	53	
	7	30.00		26	11	37	325	362	7	343	4	22	
III		28.50		20	2	22	351	8	1	354	9	11	
	1	28.00		18	0	18	358	11	0	358	11	7	
		27.00		----	----	14	365	14	0	365	14	0	

Example 48 gives the date and period constants for the phenological seasons from appendix table 9 for representative isophanes and latitudes north on the one hundredth meridian in bioclimatic major zones I, II, and III and astroterrestrial season zones I and II, as computed from average records of characterizing seasonal events in the intercontinental base area, Kanawha Farms, W. Va. (See explanation of appendix table 9.)

Under *BZ* the *Ma* major and *Mi* minor bioclimatic zones are given for the representative *isophanes* and corresponding *latitudes* on the one hundredth meridian of the Northern Hemisphere, while *SZ* gives astroterrestrial season zones I and II. Under 1 spring, 2 summer, 3 autumn, and 4 winter are given the *yd* year-date and *p* period constants for each; *1+2+3 p* gives the warm period of the year from the beginning of spring to the beginning of winter for comparison with the winter period; and *yr. p* gives the total period for the season year from the beginning of spring of one year to the beginning of spring of the next.

It will be noted that there is a definite relation between the major and minor bioclimatic zonal constants and the season zones, but that season zone II includes minor bioclimatic zone 4 of major I and part of minor 1 of major III.

EXAMPLE 49.—*Comparison of year-date constants for the beginning of the astroterrestrial and phenological seasons for representative latitudes north*

Season zone	Latitude isophane	1 spring		2 summer		3 autumn		4 winter		1+2+3	
		16	9	16	9	16	9	16	9	16	9
		d1	*1*	*d2*	*2*	*d3*	*3*	*d4*	*4*	*p*	*p*
	66.50 N.	218	175	218	210	218	210	218	235	0	60
	60.00	188	148	208	210	228	210	248	255	60	107
	57.00	174	135	204	204	233	216	263	265	89	130
	51.00	146	111	194	179	242	240	290	289	144	178
II	48.00	131	98	189	166	247	251	304	300	173	202
	43.00	107	78	182	145	254	273	327	320	220	242
	40.00	94	66	177	131	259	286	341	331	247	265
	34.00	66	42	132	74	303	332	2	354	301	312
	30.00	48	26	76	37	358	362	20	4	337	343
	28.00	39	18	48	18	20	11	29	11	355	358
	27.00	34	-----	34	14	34	14	34	14	365	365

Example 49 gives a comparison of the year-date constants for the beginning of the astroterrestrial and phenological seasons for representative latitudes in season zone II north, in which *d1*, *d2*, *d3*, and *d4* are for the astroterrestrial seasons of table 16, north, and 1, 2, 3, and 4 for the phenological seasons of table 9, north. Under *1+2+3*, *p* gives the warm period in days as represented in tables 16 and 9.

In this comparison it is to be kept in mind (1) that the astroterrestrial constants are based on the astroterrestrial law of the seasons and apply to latitude alone across the continents in astroterrestrial zone II, while the phenological constants apply to the isophanes of bioclimatic law relative to the phenological records of the intercontinental base area, and (2) that both tables apply to the beginning of the four seasons for the continents of the Northern Hemisphere.

BIOCLIMATIC CONSTANTS

Bioclimatic zonal constants for the seasons, as already noted, are the *thermal* and *phenological* constants for the same latitudes or isophanes, but, instead of representing the latitude element of the astroterrestrial law and its requirements alone, they represent the latitude and longitude elements of the bioclimatic law and its isophane requirements.

LAW OF THE TERRESTRIAL SEASONS

While the major causes of the terrestrial seasons are the same as those represented by the astronomical and astroterrestrial, they are profoundly modified by the distribution of the land and water of the surface of the earth, and the elevation of the land above the level of the sea.

The fundamental principles of the law of the terrestrial seasons correspond with those of the law of the astroterrestrial seasons in the three zones of the seasons of the Northern and Southern Hemispheres, but differ in that the poleward and equatorward limits of the former on a sea-level basis correspond to the isophane principles of bioclimatic law instead of to the latitude principle of astroterrestrial law. They also differ radically, as applied to altitude of the land above sea level, in that all of the terrestrial seasons may occur in the same latitude, as limited by altitude alone. There are, however, corresponding relations between the terrestrial and astroterrestrial season constants in the perpetual summer of zone III, perpetual winter of zone I, and progressively shorter periods of spring, summer, and autumn, and of the warm period of the year with higher latitude in zone II north and south poleward. The difference of special significance is the variability in dates of beginning and length of the terrestrial seasons in given latitudes as compared with the constants of the astroterrestrial seasons for the same latitudes.

THE TERRESTRIAL SEASONS AND SEASON ZONES

In the further classification of the terrestrial seasons (order C) it is important that special attention be given to the minor divisions in which are found the more specific and significant characterizing elements of the minor zones, types, and kinds of seasons as they effect human interests.

As outlined in the classification of bioclimatic and season zones (p. 96), zone I includes two minor divisions of the terrestrial seasons, one polar from near the Arctic and Antarctic Circles to the poles, and the other alpine from near snow line to the summit of high mountains in any latitude above sea-level zones II and III. Each of these minor divisions is characterized by a short cool spring-autumn season with no summer toward the lower latitude limit of the polar and the lower altitude limit of the alpine zone, in which polar and alpine vegetation develops from flowers to seed under a much

lower effective temperature (in zone I) than is required by vegetation in zones II and III.

Zone II is the zone of the four distinctive seasons, as characterized by average monthly or daily mean temperatures (appendix schedule 2) with (1) the beginning of spring ranging from 35° F. poleward to 45° equatorward, (2) summer from 55° poleward to 64° or 66° equatorward, (3) autumn from 55° poleward to 64° equatorward, and (4) winter from 35° poleward to 43° equatorward.

In zone III, including alpine zones I and II, there are three more or less distinctive seasons as controlled by altitude of the land above the sea and as characterized by average temperature. They are (1) perpetual warm season above about 68° F. as the monthly mean of the coldest month, (2) perpetual cool alpine season at altitudes above the zone of perpetual summer, with means below 68° for the coldest month to about 45° for the warmest month, and (3) perpetual cold alpine season below about 45° for the warmest month from near and above snow line to the altitude limit of the land.

KINDS OF SEASONS

Of the many kinds of terrestrial seasons, as distinguished by general or specific seasonal phenomena, those of special importance include (*a*) *thermal seasons,* as characterized by one or more thermal elements; (*b*) *frostless seasons,* based on the dates of spring and autumn frosts; (*c*) *phenological seasons,* as characterized by dates of periodical events marking the beginning and ending of the regular seasons; and (*d*) *biological seasons,* the periods of seasonal development and activities of species of plants and animals.

Wet and dry seasons are characterized by more or less periodic wet and dry periods in all of the major zones, but especially in zone III.

Of the many types of seasons those characterized by (*a*) abnormally long or short, cool or warm, spring, summer, or autumn; (*b*) long or short, cold or mild winters; or (*c*) extremes are of special interest and are usually associated with such types of climate as marine, coastal, mountain, continental, etc., and corresponding types of zones characterized by the relations between the *a*, *w*, and *c* variations from the thermal mean constants of table 3.

There are also regional and local types of seasons as the effect of peculiar physical and especially topographic features of the surface of the land. *Geographic* seasons have special reference to the geographic distribution and zonation of seasons and types of seasons on different continents and in their coastal, mountain, and interior regions.

CHARACTERIZING ELEMENTS OF THE TERRESTRIAL SEASONS

The major characterizing elements of the terrestrial seasons and their types are thermal, phenologic, and geographic.

The thermal elements which characterize the thermal seasons are (*a*) the average of the means for the year; (*b*) the sea-level annual and monthly isotherms; (*c*) monthly or daily means for the beginning of spring, summer, autumn, and winter; (*d*) absolute maximum for summer; (*e*) absolute minimum for winter; (*f*) effective sum of the monthly means: and (*g*) killing frosts with average dates of latest in spring and earliest in autumn, and the period between these dates.

The time elements which characterize the phenological seasons are the dates and periods of seasonal events of plants and animals with average dates of specific or group events for the beginning of spring, summer, autumn, and winter, and average periods in days for each.

Among the characterizing elements of the geographic seasons are those relating to their geographic distribution or zonation, as (1) the determined latitude and altitude range and limits of the zones of the seasons, and (2) the determined geographic distribution of seasons and seasonal types of the same general length and character as related to hemispheres, continents, major and minor regions, and local areas.

CONSTANTS AND VARIABLES OF THE THERMAL TERRESTRIAL SEASONS

CONSTANTS

The principal thermal constants for the thermal terrestrial seasons are the same as those for the astroterrestrial seasons: (1) the thermal means—appendix table 3; (2) sea-level isotherms with dates and period constants for the poleward and equatorward movements in time with distance in degrees of latitude—appendix table 16; (3) frostless seasons between the dates of latest killing frost in spring and earliest in autumn—appendix table 6; (4) the thermal effective sum, or sum of degrees of the monthly mean temperature above the indices 35, 40, and 43° F.—appendix table 5; (5) thermal types of the seasons by the constants of the mean maximum and minimum of the year and of the warmest and coldest months, and the absolute maximum and the absolute minimum for the year—appendix table 4 and appendix schedule 1; and (6) the monthly or daily mean indices—appendix schedule 2.

VARIABLES

The variables are the position records for comparison with the thermal constants of the tables or with a schedule of nonconstants, also as represented by the averages of thermal records at a representative geographic position, or of two or more record positions within a local or general area

The variables for the isotherm constants are the average record latitude positions of the monthly sea-level isotherms taken to represent the middle of the month for comparison with the corresponding latitude of appendix table 16, and the normal daily or monthly means to represent the beginning of each season with the dates on which they occur (for comparison with the constants of table 16), to find, as with other variables, the variations from the latitude requirements of astroterrestrial law.

CONSTANTS AND VARIABLES OF THE PHENOLOGICAL SEASONS

In addition to the date and period constants of table 16 the standard date constants for the beginning and ending of the four seasons and the different stages of each are given in appendix table 9 for the northern zone II. A similar table of constants might be computed for southern zone II (see explanation of appendix table 9).

Phenological variables corresponding to given constants include averages of recorded dates of seasonal events at any geographic position or place and the periods in days between dates with reference to a single plant or animal or to any group of plants or animals that is representative of the beginning or ending of any seasonal phenomenon or agricultural practice.

The same principles apply to the constants and variables of the geographic seasons.

BIOCLIMATIC ZONES

In the preceding sections references are made to the zonation of life, climate, and the seasons. It is, therefore, the object of this and the following section to outline (*a*) the history and development of the concept of geographic zones, (*b*) the laws and principles involved, (*c*) the author's conception of the bioclimatic zone and zonal type, and (*d*) the development of systems and methods of application with additional test examples, charts, etc.

HISTORY AND DEFINITIONS

In the literature on climatic and life zones, for a long time the only recognized major climatic zones were five uniform belts around the world as limited and bounded by the tropical and polar circles; these were designated as two north and south frigid, two north and south temperate, and one torrid or tropical.

Later it was recognized that these major zones were merely expressions of major astronomical effects and that, as characterized by the major distribution of climate, plants, and animals, they were not limited by parallels of latitude but more nearly by sea-level isotherms. Still later it was assumed, with special reference to the zonation of life on the continent of North America, that they were limited to given sums of so-called effective temperature of the season of growth and reproduction.

Thus at first only major zones were recognized, based solely on astronomic control, without regard to modifications by the surface features of the earth. The more recent recognition of the major modifying factors led to the interpretation of major and minor zones in terms of temperature, climate, and life, limited by altitude as well as by latitude. Thus the later concepts revealed in literature are very different from the earlier one, in that little regard is given to range and limits by latitude alone.

Progress in the development of the modern ideas of life and climatic zones is represented in special publications on the geographical distribution of life, climates, etc., including some comprehensive systems of classification of climates in works on climatology; while general information is found in standard works on geography, physiography, meteorology, and biology. Those readers, therefore, who may desire further information on the historical development of the subject are referred to the original sources. The subject, as here discussed, is from a bioclimatic and quite different point of view.

The term "zone" as applied to geographic distribution was, in its original meaning, a belt of prevailing similar climatic and biologic conditions between parallels of latitude around the earth. According to the modern concept and general usage, however, a zone may be defined as any area of land or water which is distinguished or characterized by one or more climatic, seasonal, or biologic elements. The major purpose of a designated zone and the interpretation of its geographic significance is to serve as a basis of reference in comparative studies of its climate, seasons, plants, and animals.

A *terrestrial zone*, as distinguished from a *marine zone*, is a continental and insular area of the surface of the earth, but it generally includes any minor fresh-water lake, pond, or stream within its specified boundaries.

A *thermal zone* is characterized by temperature without regard to other characterizing elements of climate, life, or seasons, because within the same range of temperature many very different types of climate, life, and season may prevail.

A *climatic zone* is characterized by a certain general combination of major and minor climatic elements including temperature. It differs in its range and limits from the corresponding thermal zone in that different elements of climate are involved, such as rainfall, prevailing winds, etc. Thus a climatic minor zone or zonal type may represent west coast, mountain, interior, east coast, and other regions, which may include sections of two or more minor or even two major thermal zones.

A *season zone* is characterized by the beginning, length, and distinctive features of the seasons of the year, and because of the effect of similar causes it agrees closely with the bioclimatic zone.

A *life zone* is characterized by the prevalence of given species and groups of plants and animals.

A *bioclimatic zone* is a major or minor terrestrial area characterized by a combination of broad, general, but distinctive elements of life, climate, and seasons of the year but always with variable ranges and limits, in general accordance with the requirements of bioclimatic law. Under this law *there are no sharp lines of distinction between the limits of any two major or minor zones as defined by the geographic coordinates.* This is because of the range of variability in the distribution of characterizing elements as the effect of varying regional and local physiographic factors which serve to modify the general and specific requirements of the law. Thus, while bioclimatic zones may be represented in a broad general way on a map of a continent, region, or political division, *specific interpretation of minor zones, zonal sections, and types to be most reliable must be restricted to local areas and geographic positions.*

Under the broader interpretations of the general characteristics of similar types of plants and animals of different regions of the continents there is, under the same range of average temperature, a close relation between (*a*) the minor thermal, climatic, season, and life zones and zonal types of one region of one continent, and (*b*) those of another region of the same or similar physiographic and climatic conditions of any other continent.

LAWS AND PRINCIPLES OF THE ZONATION OF LIFE AND CLIMATE

With reference to the preceding definitions, it is desirable to briefly review the general subject of the laws and principles of the zonation of life and climate, both from the bioclimatic point of view and from some of the points of view of other authors, as represented in the literature.

ASTRONOMIC LAWS

As stated in the preceding sections, the major laws of causation relative to bioclimatic phenomena are represented by the motions of the earth relative to the position, light, and heat of the sun, with the major laws of effect represented by gradations from the heat and related phenomena of the major tropical zone to the cold and related phenomena of the major frigid zone.

These major laws of cause and of effect are fundamental to the whole subject of the zonation of life and

climate; and whether specified or not have been the basis for all scientific consideration of the subject. The modification, however, of the major and minor effects by the unequal distribution of land and water, and elevation of the land above the sea, is very profound and varied.

As distinguished from astronomic law and its fundamental effects on the climate of the world and in the broader phases of the geographic distribution of terrestrial and marine plants and animals, there appear to be three sets of minor laws of modification which relate to the surface of the earth and its atmosphere. One set is represented by the effects on marine, another by the effects on terrestrial, and the third by the interrelated effects on both marine and terrestrial life and climate.

TERRESTRIAL LAWS

Since bioclimatics deals specifically with terrestrial phenomena we are more directly concerned with the second and third sets of laws of modification; and, since the subjects of ocean currents and the physics of the air are fully discussed in standard works and special papers by authoritative authors, the following discussion will relate more specifically to *effects* rather than *causes* of modification as revealed by terrestrial life, climate, and seasons.

LAWS OF TEMPERATURE

Fundamentally, temperature is one of the major effects of astronomic cause, modified first by interrelated marine and terrestrial, and finally by major and minor terrestrial, factors down to the local causation-factor complex of the specific place where the temperature is observed and recorded.

There is a most extensive literature on the general and specific relations of temperature to climatic and biologic phenomena, and many principles and laws have been proposed relative to temperature control of the geographic distribution of plants and animals, the zonation of life and climate, etc. These include under the subject of temperature control (*a*) the sum total of heat required for the development of vital processes; (*b*) the zero or vital temperature; (*c*) the effective sum of daily temperature; (*d*) the summation process; (*e*) the remainder indices; (*f*) the exponential indices; (*g*) the physiological indices; and (*h*) Linsser's law.

MERRIAM'S LAW

Among the examples of general interpretation and application of the thermal element as related to the zonation of life, that of Merriam [24] deserves special mention.

The principles proposed by Merriam for the interpretation of geographic limits in the distribution of plants and animals in North America are (1) that *the northward distribution of terrestrial animals and plants is governed by the sum of the positive* (daily) *temperatures* (above the normal daily mean of 43° F.) *for the entire season of growth and reproduction;* and (2) that *the southward distribution is governed by the mean temperature of a brief period during the hottest part of the year.* On this basis he established the life zones of table 1.

[24] MERRIAM, C. H., LAWS OF TEMPERATURE CONTROL OF THE GEOGRAPHIC DISTRIBUTION OF TERRESTRIAL ANIMALS AND PLANTS. Natl. Geog. Mag. 6: 229–238, illus. 1894.

——— LIFE ZONES AND CROP ZONES OF THE UNITED STATES. U. S. Dept. Agr., Div. Biol. Survey Bull. 10, 79 pp., illus. 1898.

TABLE 1.—*Governing temperatures of the zones*

Region	Zones	Governing temperatures: Northern limit; sum of normal mean daily temperatures above 6° C. (43° F.)		Governing temperatures: Southern limit; normal mean temperature of 6 hottest consecutive weeks	
		° C.	*° F.*	*° C.*	*° F.*
Boreal	Arctic			[1] 10	[1] 50
	Hudsonian			[1] 14	[1] 57.2
	Canadian			18	64.4
Austral	Transition	5,500	[2] 10,000	22	71.6
	Upper Austral	6,400	11,500	26	78.8
	Lower Austral	10,000	18,000		
Tropical		14,500	26,000		

[1] Estimated from insufficient data.
[2] The Fahrenheit equivalents of centigrade sum temperatures are stated in round numbers to avoid small figures of equivocal value.

TEMPERATURE AS A GENERAL INDEX

While it must be recognized that temperature is only one element of the complex of cause and effect and is not in itself a specific controlling cause of life processes and phenomena, it is a very important index to the causation complex and the relative intensity of the factors of this complex as represented by observed effects. In other words, *temperature* is so interrelated and correlated with other effects of major and minor causes, as represented by all of the elements of the climate, seasons, weather, and life of a place, that when properly recorded and interpreted it *becomes the most reliable index to a preliminary interpretation of the geographic zonation of the bioclimatic features of the surface of the earth.* Indeed, as has been indicated in the test examples already given, and, as will be shown later, *it is by the thermal index that preliminary interpretations are made of the minor zones for representative geographic positions and for the limits and range of the major and minor zones of the continents.*

PRINCIPLE OF THE THERMAL MEAN CONSTANT

Assuming (1) that the long period average or normal mean temperature for the geographic position of a meteorological station expresses in a general way the modified effects of the local causation-factor complex; (2) that the average of the means for representative positions within a given area expresses the thermal character of the regional complex; and (3) that the relations between the recorded annual, warm, and cold monthly means and their variations from a requirement position constant are indices and measures of the relative intensity of the modifying influences; then it is plain that an application of the thermal mean indices can be made to serve as a guide to the interpretation of bioclimatic phenomena in general and of zones and zonal types in particular.

CONCEPTION AND DEVELOPMENT OF THE THERMAL CONSTANT PRINCIPLE

In connection with a study of the distribution of insects and plants in West Virginia begun in 1890, and with a further study of the relation of temperature to Merriam's life zones as applied to the State, begun about 1895–97, the writer utilized the available recorded normal monthly means of record positions of the Atlantic States and West Virginia, with averages for the period between March and August inclusive for each 1° of latitude and applied them as an experimental index to the latitude and altitude limits of the zones, as characterized by native trees, with special reference to the Allegheny Mountains. From these data it was con-

cluded that each of Merriam's zones (Canadian, Transition, and Upper Austral) as represented in West Virginia was characterized by a fairly defined range in the normal mean temperature for the March to August period. It was apparent on this basis that (*a*) for the upper limit of the Upper Austral zone the mean temperature for the period should not fall below 62.2° F.; (*b*) for the Transition zone it should not fall below 60.5° F.; and (*c*) for the Canadian zone it should not go above 60.5° F. It was further indicated that the altitude limits so defined were progressively higher southward at about 2,400 feet between latitudes 39°30′ and 39°45′, and about 3,200 feet between latitudes 37°30′ and 37°45′; variations from the altitude constants to be expected for given types of soil, slopes, etc., are to be added or subtracted as a correction for local influences. On this basis the corresponding rate in temperature for latitude and altitude is about 1.1° F. to 1° of latitude and 400 feet of altitude.

This index map represents the writer's first conception of the principle of a thermal mean constant for application in the preliminary interpretation of the

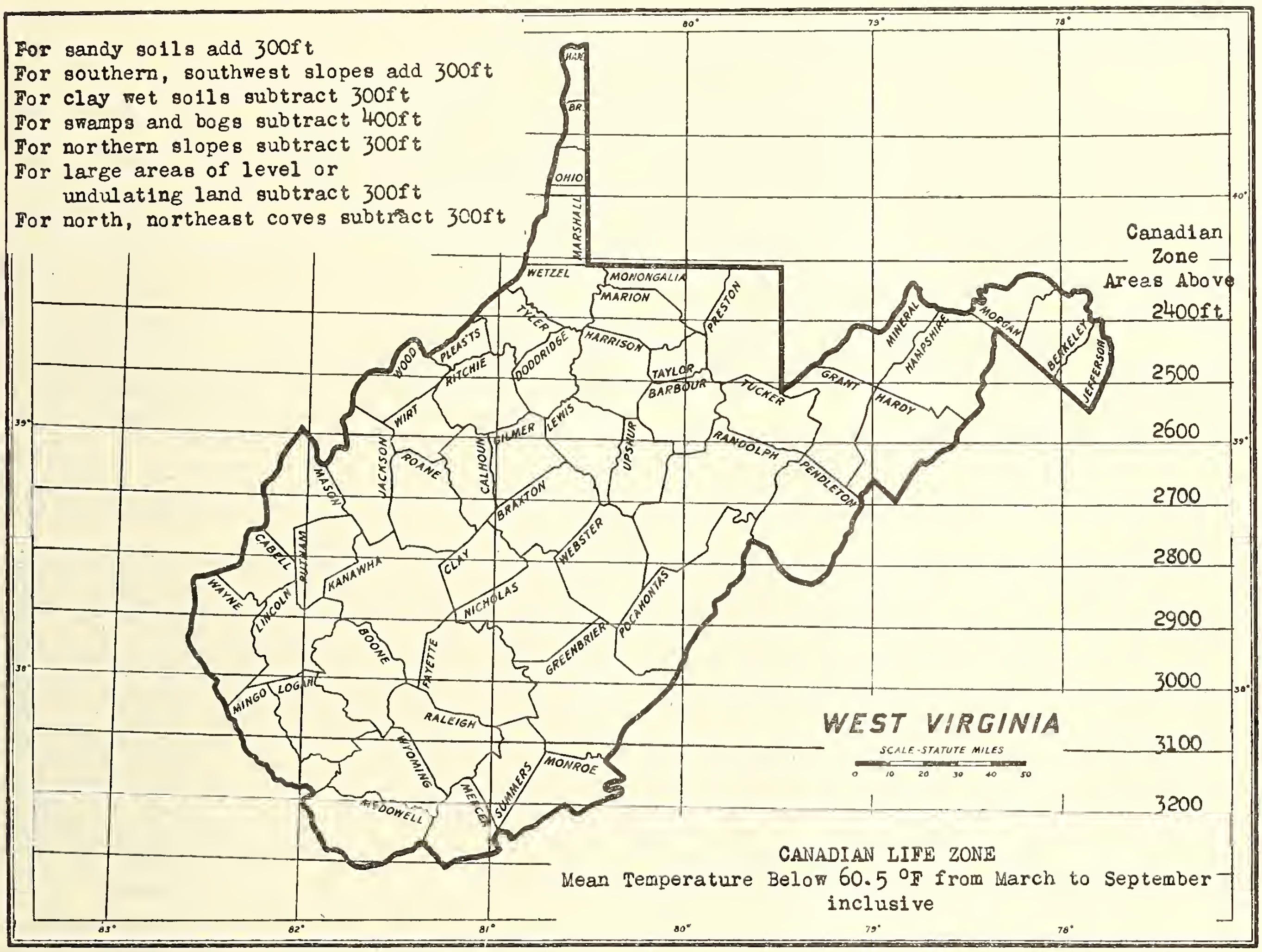

FIGURE 33.—Map of West Virginia with lower altitude limits for the Canadian life zone as indicated by the thermal mean index 60.5° F.

at the general average rate of 100 feet to 15 minutes of latitude.

This conception of a principle of thermal mean constants for defining zonal limits at a given unit rate of variations for altitude and latitude was represented on an outline map of the State, of which figure 33 is a copy of the one for the lower limit of the Canadian zone.

This outline map with parallels at intervals of 15′ of latitude shows that the average altitude constants above sea level for the lower limit of the Canadian, and upper limit of the Transition, life zones, in the given latitudes as characterized by the period average constant of 60.5° F., is based on the theory that southward from the northern border of the State this limit ascends to a higher altitude at the general average rate of 100 feet to each 15′ of latitude, and that, therefore, under average conditions, the lower limit of the zone should be found range and limits of life zones in accordance with a given unit constant rate of variation in temperature with distance in latitude and altitude; and it was on a further development of this principle that the idea of a bioclimatic law of latitude and altitude was based and proposed for application as a guide to the date to seed winter wheat at different places in the State to avoid damage by the hessian fly. (See Bibliography, p. 12.)

Subsequent studies of the altitude limits of the zones of the State as characterized by given species of plants showed that in general they agreed with those indicated by the thermal mean, for example, the upper limit of the Transition and lower limit of the Canadian zones, characterized by red spruce.

As a result of a general survey of the State to determine the altitude range of characterizing species in different latitudes and altitudes and to verify the appli-

cation of the principle represented in figure 33 a preliminary map of the life zones of West Virginia was published in 1897 [25]. Continued studies up to 1902 served to establish the principle of a general average unit constant rate of variation in altitude limits of the zones from the higher to the lower latitudes within the State, and that there were coordinate relations between unit rates in temperature, time, and distance.

Long continued studies and development of the principle of the thermal mean index to the bioclimatic zones led about 1919 to the adoption of the modified thermal indices of *a* the normal mean for the year to indicate the thermal range of the major and minor zones, *w* the normal mean of the warmest month, and *c* the normal mean of the coldest month, as published in 1920 [26]. Further studies of the principles outlined in this paper led to further modification and revisions.

PRINCIPLE OF THE MODIFIED THERMAL MEAN CONSTANT INDEX TO THE RANGE AND LIMITS OF THE THERMAL ZONES

The results of studies and development of the principle of the modified thermal mean constant index to the isophane range in latitude degrees are represented in appendix table 3, in which the sea-level isophane ranges of the major and minor zonal constants, as given in the scale of zones, are characterized by corresponding ranges in the *a*, *w*, and *c* thermal constants. Under the requirements of bioclimatic law and this principle it is shown that:

1. The record *a* average annual temperature coming within the range of the *a* constants for a given major or minor zone indicates that the record position is in that zone so far as it is characterized by the annual temperature.

2. The record *w* mean of the warmest month coming within the range of the *w* constant for a given zonal constant indicates that the record position is in the *w* *warm type* of the indicated *a* zone of the same position.

3. The record *c* mean of the coldest month coming within the range of the *c* constants for a given zone constant indicates that the record position is in the *c* *cold type* of the *a* zone of the same position.

4. Since the low and high limits of a zone are controlled by complex factors measured in terms of heat and cold elements of the average temperature, the normal mean of the warmest month represents the warmer, and the normal mean of the coldest month represents the colder, part of the average annual temperature; and *therefore the relative intensity of the record heat and cold serve to indicate a modification of the a zone.* Thus the normal mean of the warmest month is designated as the *w warm mean index* to a higher or lower warm zonal type, while that of the coldest month is designated as the *c cold mean index* to a higher or lower cold zonal type, than that represented by the *a* index.

5. The principle of the *a*, *w*, and *c* indices to the zones and zonal types of a given record position involves the principle that the equatorward and lower altitude limits of the distribution of species of animals and plants adapted to higher latitudes and altitudes are controlled by heat, and that the poleward or higher altitude limits of distribution of animals and plants adapted to lower latitudes and altitudes are controlled by cold; or in other words, controlled by the causation complex which modified the *a*, *w*, and *c* temperatures.

This principle applies to the author's zonal types in which the record *w* and *c* means coming within the range of the same *a* zonal section indicate that the *w* and *c* types are normal or the same as the *a* zone; but if the *w* or c records indicate a higher or lower zonal section or minor zone than that indicated by the *a* record, they indicate a higher and colder, or lower and warmer, zonal type of the record *a* zone.

6. Additional warm and cold zonal types are indicated by different warm and cold thermal elements, such as those in appendix table 4, in which *d* the normal mean maximum temperature for the year, *e* the normal mean maximum temperature for the warmest month, and *f* the absolute maximum for the record period indicate warm types. In appendix table 5, *j* the sum of the monthly means above a given thermal index, as 35, 40, and 43° F. for the warm period of the year indicates thermal sum types; while in table 4, *h* the normal mean minimum temperature for the coldest month, *i* the normal mean minimum temperature for the year, and in appendix schedule 1, *g* the absolute minimum temperature for the record period, indicate cold types.

Since the unit constant rates for each of these thermal elements per unit of distance in isophane and altitude except *g* is a determined coordinate of the bioclimatic law, they are utilized to compute standard tables of thermal and distance constants and charts to represent the requirement thermal and zonal constants of the law for the sea-level isophanes across the continents of both the northern and southern hemispheres, as in appendix tables 3, 4, and 5. Since the tables of thermal constants are computed by the modified unit rate constants, they meet the requirement effects of higher and lower isophane and altitude positions.

Appendix table 3 serves as the best and most serviceable example of the principle of the modified thermal constants to determine variations in bioclimatic effects with higher and lower isophanes relative to a given base. The primary object in the development of this table was to represent zonal constants for sea-level ranges in isophanes, as characterized by the *a*, *w*, and *c* thermal constants, in order that these constants could be compared with the *a*, *w*, and *c* position records for the interpretation of the *a* zone and the *w* and *c* zonal types represented by the record position, and also for interpretations of nonrecord positions of the same local region, as shown in the many test examples.

TEMPERATURE AS A MEASURABLE EFFECT

From the foregoing it will be recognized that temperature is the most important measurable effect of the local causation complex because (1) it is more or less modified by one or more of the elements of this complex; (2) this modification is reflected and interpreted in record degrees centigrade or degrees Fahrenheit; (3) the relative intensity of the modifying factors is measured by the variation of the recorded average from the requirement constant of the bioclimatic law; and (4) the record normal mean temperature of a place coming within a given thermal range constant for a given minor zone indicates that the place is within the limits of that zone, regardless of the variation from the requirements of the law. In other words, the modification of the temperature is so correlated with the modification of the general characteristics of the zone as to serve as a reliable index to the minor zone represented by a given record position.

ZONAL TYPES

Under the classification of zonal types it will be seen that within a given minor *a* zone, as characterized by

[25] Hopkins, A. D. Report of the entomological department. W. Va. Agr. Expt. Sta., Ann. Rept. 9: 117-129, maps 1-2. 1897.

[26] Hopkins, A. D. Modifying factors in effective temperature; or a principle of modified thermal influence on organisms. U. S. Monthly Weather Rev. 48: 214-215. 1920.

average temperature alone, there is a wide range of types which represent the modified effects of different combinations of factors. Each of these types, while coming within a certain range of temperature, is also characterized by some other element or combination of elements of the climatic and biologic features, as in coastal, mountain, interior, humid and arid, major and minor regions, plant and animal types, etc., but each of the widely varying types will have one or more characteristic features to indicate the major and minor bioclimatic zone to which it belongs. Nevertheless the thermal range constant and record *a* mean form the most important single index for universal application in the preliminary interpretation of the major and minor zones.

THE THERMAL SUM INDEX

The principle of the modified thermal sum index within a given minor zone is represented in appendix table 5, which under the requirements of bioclimatic law corresponds to the modified thermal *a*, *w*, and *c* constants of table 3. This principle differs from other principles of the thermal sum and of the thermal range in that it is based on the sum of the monthly means above given zero units for specific ranges in isophanes. (See explanation of table 5 and examples of application.)

COMPARISON OF MERRIAM'S SUMMATION HEAT PRINCIPLE WITH THE MODIFIED THERMAL MEAN INDEX PRINCIPLE

The procedure in the application of Merriam's principle is (1) to plot the season sums of the normal daily means above 43° F. for representative record positions on a map and then connect the positions of equal sums by lines to represent season isotherms; and (2) to plot the mean normal temperature of the 6 hottest consecutive weeks and connect those of equal amounts by lines to represent the heat isotherms.

The application of this principle involves much labor in computing the thermal sums, which can serve only as preliminary interpretations to be supplemented by detailed surveys to determine the presence or absence of typical species of plants and animals to serve as further characterizing elements of the zones.

The results of these thermal and biologic methods of interpretation were presented by Merriam in his contributions of 1894–98 and have demonstrated beyond reasonable doubt the scientific and economic importance of the life zones as a guide to successful agricultural practice. It is shown also that there is a clearly recognizable relation between the life zones as interpreted by Merriam and the specific requirements of his thermal principle.

The modified thermal mean indices to the interpretation of bioclimatic zones conforms in general to the law of so-called temperature control of the zonation of animals and plants, but there is a radical difference in methods of procedure, in that by means of a system of thermal and zonal constants (as table 3) the normal annual mean of a record position serves as an index to its major and minor zone, the normal mean of the warmest month as an index to the warm type, and that of the coldest month as an index to the cold type to be expected at the given record position.

Extensive studies and tests have been made of this principle, and zonal maps of the United States have been prepared. The thermal or bioclimatic zones on these maps show sufficient agreement with the life zones of Merriam, which are based on results of detailed biologic surveys, to verify the thermal index principle and indicate its value.

The notable difference between the minor bioclimatic zones of major II, or temperate zone, of the United States (as indicated by the thermal index) and the life zones of Merriam is in the addition of a transition minor zone 5 between the upper and lower Austral life zone. There are also some differences in the interpreted latitude and altitude limits as represented on a map. The essential and most important difference, however, is in the principle and method of interpretation, but even with this marked difference in method there is a remarkably close agreement between the results.

While the biologic index is useful for interpreting the distribution of groups of plants and animals both in bioclimatic zones and in Merriam's life zones, the bioclimatic zones are determined for *specific geographic positions* and are represented on outline maps merely to give a general picture of the general areas and regions in which certain zones prevail.

The distinctive feature, however, of the bioclimatic principle is in the use of thermal, time, distance, season, weather, and biologic elements in the interpretation of the zonal types of a given minor zone, and in the analysis of such type elements for a given position. The essential thing is that the thermal and bioclimatic indices be made available for immediate preliminary interpretation of facts and evidence. The information thus obtained cannot be secured so efficiently by any other method.

THE ZONAL ELEMENTS

THE ELEMENT OF TIME

The element of time, as related to the zonation of life and climate, is represented by the dates of the standard calendar, periods in days between dates, the relative length of daytime and nighttime, and by geologic and recent periods.

GEOLOGIC TIME

The fossils left in the rocks of different geologic periods indicate that there have been many profound changes in the climate and life of the surface of the earth accompanied by radical changes in geographic distribution and zonation. Whether these radical changes were caused by major changes in the distribution of land and water or by some change in the astronomic system, and whether the major terrestrial distribution of the climatic and biologic elements was then in accordance with bioclimatic law, must be left to the ultimate decision of authoritative specialists, but the recognition and application of bioclimatic principles will doubtless help to solve some of these problems.

As applied to the present climates and seasons of the continents and their zonal distribution, it would seem probable that there have been no major and but few minor changes since the last glacial period. It seems probable that the present major zonal distribution of plants and animals must have been established at a much later time than that of the climates and seasons, which were evidently the immediate effect of the established relations of land and water. Although it must have required a very long period of time for plants and animals to become adjusted to the new environment, the characterizing life of the major zones, especially that above the tropical zone, probably was established comparatively late in recent geologic time. If so, the present distinctive biologic features of the minor zones and types represent only minor changes in the characterizing elements, especially in regions and local areas where the

natural features have been more or less modified by human agencies.

Thus, as related to the present concept and classification of zones, it is evident that in preceding geologic time what is now recognized as major III extended through what is now major II and even into major I, and that at another time major I extended far into major II and was represented far more extensively than now in the high elevations of major III.

Since the same fundamental laws of causation represented by the motions of the earth, solar energy, etc., must have prevailed from the first appearance of distinctive forms of life, together with the same or similar minor laws of modification, it may be assumed that at least some of the major effects were in accordance with bioclimatic and other laws similar to those now recognized. If so, it may be possible to interpret in a general way from paleontological evidence the changes in bioclimatic zones of geologic time as related especially to certain well-marked land areas and to deduce from these the probable relations between major areas of land and water in different geologic periods.

Recent geologic time may be designated, therefore, as that in which the distribution and activities of prehistoric, primitive, and historic civilized man have had an influence in bringing about changes in the geographic distribution of plants and animals, and to some extent minor changes in local climate. Thus the present period represented by published records may be designated as "historical" time; but, as measured in geologic time, this period and its records are very recent.

PRINCIPLE OF THE TIME CONSTANT

The principle of the time constant includes the elements of the seasons and the dates and periods of events in the seasonal development of plants and animals as related to the zone and zonal types represented by a local area or place. In this relation the average date of a seasonal event, the average period in days between seasonal events, beginning and ending of the seasons, etc., independently or correlated with the thermal and distance elements, serve as indices to the zone or zonal type represented by a record position. As in the thermal principle, the time principle of zonal indices is shown in tables of time constants, in which the date constants for a given subject represent the isophane range and limits of the zonal constants. Thus a record average date, e. g., the wheat seeding date, corresponding with a date constant in the table, indicates the wheat seeding zonal type.

THE SEASON INDEX

Since the average date for the beginning or ending of a given season and the length of the period in days varies with the geographic position, and since in general the variation is in accordance with the requirements of bioclimatic law, seasonal periods (especially the warm period) serve to indicate the season type of zone of a record position.

PRINCIPLE OF DISTANCE ELEMENTS

The elements of distance as related to the thermal and bioclimatic zone are represented by the geographic coordinants (latitude, longitude, isophane, and altitude), in which degrees of latitude or isophane and feet of altitude are utilized as units of measurement. The sea-level range and limit constants of a table of constants are characterized by ranges in latitude degrees and in thermal or time constants, as in tables 3 and 9.

Thus to find the zonal constant for a given geographic position, the position altitude (*pa*) is reduced to *le* equivalent latitude degrees (*pa* ÷ 400 feet equals *le*), which plus the position isophane gives the *ei* the isophane at sea level equivalent to the position altitude above sea level, and this *ei* gives in any table of zonal constants the zonal constant for the position. Then the position time or thermal record referred to its corresponding constant in its respective table gives the record zone or zonal type and the *ri*, and the difference between *ei* and *ri* gives the variation of the record from its constant in equivalent degrees of latitude. Thus the zonal constant can be determined for any position with known geographic coordinates on any continent, and the zone or zonal type can be interpreted for any position for which thermal or time records are available.

CLIMATIC TIMBER LINE AND SNOW LINE

Climatic timber line and snow line for either high latitudes at, or high altitudes above, sea level are the most important indices to the range and limits of the major and minor zones, in which the altitude of snow line indicates minor zone middle 4 of major I and the altitude of timber line the colimit of minor zones 1 and 2 of major II.

These snow-line and timber-line indices apply to sea-level positions at high latitudes and to high altitudes in the equatorial regions of all continents. They are of special interest in that they serve as examples of modified effects of the continental, regional, and local causation complex during recent geologic time. Thus in connection with the thermal, time, and biologic elements, timber line and snow line represent a fundamental guiding principle for the interpretation of the zones represented by high latitudes and altitudes. (See test examples in part 1.)

CLIMATIC ELEMENTS OF THE ZONES

As has been repeatedly emphasized, the most important element of climate in characterizing the bioclimatic zones is temperature; specific ranges of the normal annual mean for a period of years serve to characterize the major and minor thermal zones, while other thermal elements serve to characterize the climatic and zonal types.

Since the average temperature is the only constant element of climate by which the thermal elements of the major and minor zones of a place or region can be interpreted, and since temperature is the basic index to the bioclimatic zones, there is a coordinate relation between the climatic, season, and life zones, as defined and classified in example 50.

As related to the bioclimatic zones, the elements of climate—other than the average temperature—represent the modified effects of many minor astronomic and terrestrial causes. These elements are so variable that they can serve only in the characterization of climatic types of the minor zones. This principle of climatic types of zones is represented by examples and charts (so far as data are available) or in schedules (as in appendix schedules 1, 2, 3).

SEASON AND ZONE RELATIONS

As has been referred to under the season indices, there is a close relation between the terrestrial season zones and the bioclimatic zones. These season zones are characterized by the thermal indices (examples 45 and 46) and the relative length of the four seasons in major

zone II, the perpetual winter of major I, and the perpetual summer of major III (examples 47 and 48). This principle of zonal indices to the terrestrial seasons is in accordance with bioclimatic law and is illustrated and represented by tables, charts, examples, and figures.

LENGTH OF DAYTIME ELEMENT OF THE ZONES

As has been previously mentioned, there is a direct relation between the length of daytime and the unmodified zones of the astroterrestrial seasons, but since there is a more or less marked variation in the percentage of daytime for the same zone or type with variations in latitude positions, the percentage must be determined separately for each latitude. Thus, while the percentage of daytime is not a characterizing element of a zone or zonal type under varying latitude and altitude positions, it is an important element of the causation complex, applying alike to any zone or zonal type represented by a given position, regardless of its zonal constant or record zone.

This principle as related to types is shown in example 54, where the range in types of minor zone 4 for Lafayette, Ind., is from lower middle 3 to upper 5, to which 58.6 as the percentage of daytime applies alike to the position, the record zone, and to all of the zonal types.

BIOLOGIC ELEMENTS OF THE ZONES

There are many and varied biologic elements which serve to characterize a given zone or zonal type, but only such elements as relate to the dates and periods of seasonal or periodical events are available for application under the principle of the constant and variable. In other words, the dates of events and the periods in days between events in plant and animal phenomena can be utilized in tables of constants to represent the requirements of the law, while the other elements represented by species and varieties of plants and animals, their ecological associations, specific and general adaptations, etc., must be recorded and interpreted as separate facts relative to the biologic features of a given zone and zonal type at the place of observation.

As a general principle, since there are many species of plants and animals which in their natural and artificial distribution may range far beyond the limits of a single minor zone, only those species and varieties that are most constant in their characterization of the zone or type are to be observed and utilized as indices.

GEOGRAPHIC ELEMENTS OF THE ZONES

The principal geographic elements of the zones are the coordinates of latitude, longitude, and altitude which are the elements of distance in defining the geographic range and limits of the zonal distribution of life, climate, and seasons, in accordance with the general requirements of bioclimatic law.

The geographic principle is represented in the thermal, time, and distance constants which are all relative to the sea-level isophane or the sea-level isophane equivalent to the position altitude, by which (together with the record isophane) the geographic distribution of the zones and their constituent elements are determined or interpreted.

LAW OF THE BIOCLIMATIC ZONES

From the preceding outline of principles and elements relative to geographic zonation, it will be recognized that there is such order and system in accordance with the laws of causes and effects as to represent a supplementary law of bioclimatic zones. We may assume that if, with the present distribution of land and water, the land were all level at any given altitude above the sea, the major and minor bioclimatic zones would be in general accordance with the requirements of bioclimatic law, as represented on the outline map of the world (fig. 36). But under the requirements of the law of the zones, as representing the principles of modification by the unequal distribution and elevation of land, and by other physiographic factors, the zones are broken up into very irregular and often disconnected regions and areas. Thus as represented on a map to include altitude (fig. 37) they appear to have little relation to isophanes or parallels of latitude, because on high isolated mountains they appear as more or less regular belts defined by altitude alone; and on the higher mountains of the equatorial regions all of the major and minor zones may be represented in a vertical series from lower tropical major III to upper arctic alpine major I.

While these factors of a very unequal distribution, range, and limits of the bioclimatic zones may appear to disagree with any order or system, they are in fact in more or less direct agreement with the requirements of bioclimatic law, the laws of zonal distribution, and the zonation of life and climate, as has been fully demonstrated by test examples.

The significance of these verifications is in the fact that *the minor zone, zonal section, and zonal types can be interpreted for any record position of any terrestrial area of the world, and from the determined variations of the position records from the requirement constants preliminary interpretations can be made for any nonrecord position within the local region represented by the record positions and also for the region as a whole.*

CLASSIFICATION OF BIOCLIMATIC ZONES OF THE CONTINENTS

Under the laws and principles of the zonation of life, climate, and seasons, the major elements of the system are (1) 5 major zones, which have been referred to in literature under various names; (2) 15 minor zones, corresponding in general to the life zones, regions, provinces, etc., of literature; (3) 5 sections of each minor zone, designated as lower, lower middle, middle, upper middle, and upper—new concepts of minor divisions of the minor zones; and (4) zonal types of the minor zones and sections, characterized by minor thermal and bioclimatic elements of modification.

TERMINOLOGY

The terminology adopted for this new system of major and minor bioclimatic zones is that proposed by the writer in 1921.[27] With some modification and elaboration of definitions and descriptions it is given in the following classification (example 50) for universal application to all terrestrial areas and countries of the world, and for interpretation in all languages in which roman and arabic numerals are utilized.

[27] Hopkins, A. D. BIOCLIMATIC ZONES OF THE CONTINENTS; WITH PROPOSED DESIGNATION AND CLASSIFICATION. Jour. Wash. Acad. Sci. 11: 227–229.

Terminology of bioclimatic zones for the Northern and Southern Hemispheres

Major zones (old)	Minor zones
Major I (frigid)	Minors 1, 2, 3, 4.
Major II (temperate)	Minors 1, 2, 3, 4, 5, 6, 7.
Major III (tropical)	Minors 1, 2, 3, 4.

The major bioclimatic zones are designated by roman numerals to correspond in general with the old terminology for the major zones, while the minor zones are designated by arabic numerals.

The designation of major and minor zones by numerals has a decided advantage over names based on arctic and tropical regions, or on geographic and political divisions, because the numerals answer the same purpose as do names for the minor zones, and, as applied to a given country, they may be associated in its own language with any desired regional or local name without departing from the coordinate intercontinental system. The advantage of such a system is the facility it offers for comparable research results in any country where the system is adopted.

The additional essential principles of the system are:

1. The principle of thermal, time, and distance elements as indices to the isophane and altitude range and limits of the zonal constants of tables and charts.
2. The principle of the isophane equivalent to the position altitude, by which the zonal constant for any geographic position is quickly found by reference to a table of constants.
3. The principle of record thermal, time, or distance indices to the zone and types represented by a record position as applied directly or by the record isophane to the corresponding tables of constants.
4. The principle of the variation of the record or modified record isophane from the equivalent isophane to interpret and measure the relative intensity of the modifying influences of the causation-factor complex.
5. The principle of biologic indices to the major zones of the continents, or the minor zones of a region or place.
6. The principle of the zonal type as characterized by time, thermal, climatic, weather, seasonal, and other distinguishing elements, including ecological relations of plants and animals, modifying influences by man, agricultural types, etc.

EXAMPLE 50.—*System of classification of the bioclimatic zones*

BZ		Characterizing elements				
Ma.	Mi.	*Isop.*	Thermal *a* ° F.	Geographic: Regions, local areas, positions	Climatic and seasonal characteristics	Biologic: Plants and animals
+I −I	------ ------	90 60	−6.25 +33.75	North and south, polar or arctic and alpine, humid or arid, major regions of the Frigid Zone.	Severe to moderate cold perpetual winter with short spring-autumn period equatorward and sea-levelward.	Forms adapted to the cold climate and continued cold season.
+I	+1 −1	90 85	−6.25 +0.63	Arctic and alpine above perpetual snow and ice.	Severe cold, perpetual winter	Adapted to severest and continuous cold, migrant hirds rare.
	+2 −2	------ 75	------ 14.37	do	Less severe cold, perpetual winter with short moderately cold period.	Adapted to less severe and continuous cold with a few migrant birds from warmer climate.
	+3 −3	------ 66.50	------ 25.63	do (Season zone −I+II).	Less severe cold, perpetual winter with longer moderately cold period.	Adapted to less severe cold and longer moderately cold period with more migrants.
	+4	------	------	Arctic and alpine above and below perpetual snow and ice, lower transition or snow line zone.	Less severe cold, perpetual winter with longer moderately cold and short warm spring-autumn.	More abundant and varied with hardy subarctic and subtemperate shrubs and flowering plants, many migrants.
	.4	63	30.00	(Snow line).		
−I	−4	60	33.75			
+II −II	------ ------	60 30	33.75 69.85	North and south, temperate or intermediate latitudes and altitudes, major arid and humid regions of the Temperate Zone.	Varying and alternating cold and warm periods, 1 to 4 seasons, winter, spring-autumn, spring, summer, autumn, winter.	Abundant and extremely varied forms ranging from subarctic in upper to subtropic in lower sections.
+II	+1	60	33.75	High latitudes and altitudes, subarctic and alpine regions and areas above climatic timber line or its equivalent, "timber line zone."	Long cold period, long winter, short spring-autumn, to very short summer season in lower limit.	Arctic and suharctic, alpine, shruhs and flowering plants with resident and migrant hirds.
	−1	57	37.50	(Timher line).		
	+2 −2	------ 51	------ 45.00	High latitudes and altitudes, regions and areas helow climatic timher line or its equivalent.	Long cold and short warm periods, long winter, short summer, and relatively long spring and autumn.	Spruce zone, upright forest or equivalent, humid and arid shrub with corresponding animals, upper limit of agriculture.
	+3 −3	------ 48	------ 48.75	Intermediate latitudes and altitudes, transition between 2 and 4.	Cold somewhat longer than warm period, winter longer than spring, summer and autumn together.	Potato and sugar heet zone, intermediate or transition, humid hardwood or pine forest or equivalent arid shrub, and corresponding animals and agriculture.
	+4 −4	------ 43	------ 55.00	Middle latitudes and high and low land altitudes.	Cold shorter than warm period, winter somewhat longer than summer; spring, summer, and autumn suhequal length.	Cereal zone, midhumid hardwood or pine forests and equivalent arid shrub, center agricultural crops, industrial development, and human progress.
	+5 −5	------ 40	------ 58.70	Intermediate low latitudes and altitudes, transition between 4 and 6.	Cold very much shorter than warm period, summer longer than winter, spring and autumn together.	Cereal and cotton zone, transition between deciduous and evergeeen hardwood forests and arid shrub, cereal and cotton plants, corresponding animals.
	+6 −6	------ 34	------ 65.70	Low latitudes and altitudes	Warm very much longer than cold period, summer much longer than the short spring, autumn and winter together.	Cotton zone, prevailing evergreen hardwood and pine humid forests and arid shrub with poleward limit of dwarf palms in lower section.
−II	+7 −7	------ 30	------ 69.85	Lower latitudes and altitudes of the transition suhtropical zone.	Very long warm and short cold periods, very long to perpetual summer; and very short spring, autumn, and winter.	Sugarcane zone, evergreen humid forests, dwarf and tall palms and arid shruh, sugarcane, cotton, and citrus fruits.
+III −III	------ ------	30 0	69.85 89.00	Tropical and equatorial low and high land, humid and arid major regions of the tropical zone.	Warm to hot throughout the year, perpetual summer.	Tropical plants and animals, evergreen humid forests and tropical arid shrub and flowering plants.

See footnote at end of table.

EXAMPLE 50.—*System of classification of the bioclimatic zones*—Continued

BZ		Characterizing elements				
Ma.	Mi.	*Isop.*	Thermal *a* ° F.	Geographic: Regions, local areas, positions	Climatic and seasonal characteristics	Biologic: Plants and animals
+III	+1	30	69.85	Low and high land, upper transition subtemperate zone.	Very long warm and short cool periods, perpetual warm to moderately warm summer season.	Tropical and subtemperate plants and animals, evergreen humid forests, arid shrub, etc., citrus and tropical fruits, sugarcane, cotton, coffee, etc.
	.1	27	72.85	(Season zone −II+III).		
	−1	24	75.45			
	+2	--------	--------	Low and high land regions and areas of the upper middle tropical zone.	Warm to hot climate throughout the year, perpetual summer season.	Tropical plants and animals, humid forests and arid shrub, tropical agriculture.
	−2	15	81.56			
	+3	--------	--------	Low and high land regions and areas of the lower middle tropical zone.	do	Transition tropical plants and animals, humid forests, arid shrub, and tropical agriculture.
	−3	5	86.85			
	+4	--------	--------	North and south, high and low land equatorial regions and areas of the lower tropical or equatorial zone.	do	Equatorial plants and animals, humid forests, arid shrub, etc.; tropical agriculture.
−III	−4	0	89.00			

Tropical alpine majors I and II above tropical III with minor zones characterized by subequal temperature throughout the year.

Example 50 gives brief definitions of the principal characterizing distance and thermal constants and features of the various elements of the major and minor bioclimatic zones, as applied to the terrestrial regions of the Northern and Southern Hemispheres.

The given isophane or latitude range on the one hundredth meridian is that of the standard appendix tables, and the thermal range in degrees Fahrenheit that of the modified annual mean (a) constants of appendix table 3 to characterize the upper and lower limits of each major and minor zone. Thus the range of major I is from isophane 90 and −6.25° F. for the upper limit to isophane 60 and +33.75° F. for the lower limit, so that a position record annual mean coming within the given range indicates that the position is within this major zone. In other words, wherever the average temperature of a record position is −6.25° F. or lower, it represents the upper limit of major zone I, and wherever that of a record position is +33.75° F. it represents the lower limit of major zone I and the upper limit of major zone II. In a like manner an average record for a position coming within these thermal limits represents a given minor division of this zone. This principle applies in the same way to the other major zones and their minor divisions, as it does also to the upper (+), upper middle (+.), middle (.), lower middle (−.), and lower (−) subdivisions or sections of each minor zone, as given in table 3. Thus under this principle any given a normal mean record referred to the corresponding a constant in table 3 gives the *ri record isophane* in the scale of isophanes and the corresponding zone and zonal section in the scale of zonal constants. Then the difference between the *ei equivalent isophane* to the altitude of the position and the *ri* gives the variation in degrees of latitude from the thermal requirements of the bioclimatic law.

MAJOR AND MINOR GEOGRAPHIC REGIONS, LOCAL AREAS, AND POSITIONS

The term *region* in this classification may be defined as any section of a continent within any range of latitude, isophane, longitude, or altitude within the thermal range index of a given major zone. The *local area* is any general or local section of land, district, town, or city within the thermal range index of a minor zone; while any immediate station or place where thermal records are kept is a *record position*, and where records are not kept is a *nonrecord position*.

The term *arctic* applies to both the arctic and antarctic major regions; while *arctic alpine* applies to high mountains in any latitude or isophane which extend above the colimit of major zones I and II or its equivalent in biologic and climatic features. *Humid regions and areas* are those with sufficient moisture and rainfall for forests, shrubs, grass, and similar vegetation. *Arid regions and areas* are those with little or no rain, ranging from *subhumid* with scant vegetation to *desert* with none. Minor zones representing colimits of the major zones, as major I minor 4, major II minor 1, major II minor 7, and major III minor 1 are designated as major transition zones; while major I minor 3, major II minors 3 and 5, and major III minor 3 are minor transition zones.

TEMPERATE AND TROPICAL ALPINE

In this classification the characterizing ranges in temperature apply alike to the major and minor arctic and alpine zones. There is, however, a marked difference between the alpine zones above zone III and those above II or I, as characterized by mean temperature alone, in that above the upper altitude limits of major II or I the arctic alpine zone is characterized by a considerable range in temperature between the warmest and coldest months, while above the altitude limits of zone III there is but little range during the year within each of the minor zones.

GENERAL CLIMATIC AND SEASONAL ELEMENTS

The only constant climatic element that serves to characterize a given major or minor zone wherever it occurs on any continent is that of the a average temperature of the year, which includes heat and cold as represented by the w warmest and c coldest months. Thus the cold decreases equatorward from polar and lower alpine positions through major zones I and II to major III with progressively longer warm seasons, while conversely the heat decreases and the warm seasons become shorter from the equatorial lowlands to polar and higher alpine positions.

Other important elements of climate, e. g., barometric pressure, humidity, precipitation, prevailing winds, etc., are exceedingly variable as related to the same minor zone on different continents and in different sections of the same continent, so that these variable elements can serve only as indices to *zonal types* of climate.

As has been shown under the laws of the seasons and in the tables of classification, the astroterrestrial and terrestrial zones are closely related to the thermal and bioclimatic zones, in that the minor zones are characterized by the same range in latitude and altitude, ex-

cept that major season zone II is extended to include minor 4 of major bioclimatic zone I and the upper part of minor 1 of major bioclimatic zone III to provide for the requirement range constants in time (dates of the calendar) of the astroterrestrial law (example 48).

It will be noted in appendix table 9 that the beginning of spring and winter date constants are extended through minor zone 3 of major I to provide for warmer variations and an arctic and arctic-alpine spring-autumn period, as distinguished from the four seasons of bioclimatic zone II. The extension of season zone II into the upper minor zone 1 of major III is also to provide for a transition between the temperature of perpetual summer and that of spring, autumn, and the short mild winter.

BIOLOGIC ELEMENTS

The biologic elements and features which serve to characterize the major or minor zones on all continents are necessarily of a general nature. Different species and genera and even different families of plants and animals are found in the same thermal zone on different continents; while different species occur in the same zones on the same continent. In general, however, *the same or similar causation complex has the same or similar effect as to the same general types of plants and animals even where very different species are involved.* Thus, although there are sometimes marked differences as to certain species of plants or animals in major zone I, in the arctic regions of North America, north Europe, or northern Asia, and the antarctic regions of South America, and even a more striking difference between arctic alpine species of the mountains of high and low latitudes, there is always one common characteristic of the major arctic and arctic-alpine zone: there are no forests of tall or upright trees, and tundra vegetation prevails wherever the surface is not covered throughout the year with snow and ice. Different species of plants and animals (including migratory birds) are found in different regions, but adaptations, habits, and effects as to general characteristics are similar under similar zonal conditions; thus these general features serve to characterize the particular minor zone to which given resident or migrant species are limited.

Certain vegetation and culture regions are designated as zones, e. g., the *spruce zone* in minor 2 of major II, in which the genus *Picea* and related conifers prevail; the *potato and sugar-beet zone* in minor zone 3 of major II; the *cereal crop zone* in minor 4 of major II; the *transition cereal and cotton zone* in minor 5 of major II, in which there is an overlapping of cereal and other crops of minor 4 and the cotton culture of minor 6; the *cotton zone* in minor 6 of major II; and the minor *transition subtropical zone* in minor 7 of major II, in which dwarf palms, sugarcane, and citrus fruits find their poleward limits.

This principle of like cause and effect applies to all of the minor zones characterized by certain general biologic features, while the more specific regional and local features serve to characterize the types. Thus within the same minor zone, as characterized by its average temperature, there are characteristic humid, rain-forest, subhumid, arid, and desert types of plants and animals, whether it occurs in lowlands of high latitudes or alpine regions of low latitudes.

COMPARISON OF ZONAL CLASSIFICATIONS IN LITERATURE

In the literature on the classification of climatic, biologic, and other distinctive features of geographical distribution under zones, belts, regions, provinces, districts, etc., various names have been proposed for the major and minor divisions based on geographic and political divisions, groups and types of plants or animals, and on certain typical elements or combination of elements of climate, weather, seasons, etc.

From a general, comparative study of all of these systems it will be noted that there is a wide range of difference in terminology and classification relative to the same or to different continents, due largely to the different subjects, objects, and interpretations as considered from a more or less independent climatic, biologic, or geographic point of view. Also all of these systems differ from the bioclimatic system. Thus in Supan's classification of climates, the major temperature zones are defined as "one Hot Belt, two Temperate Belts, and two Cold Caps", in which the north and south poleward limits of the Hot Belt are characterized by isotherm 20° C. (68° F.) of the mean annual temperature, while the poleward limits of the Temperate Belts are the same as the equatorward limits of the Cold Caps as characterized by isotherm 10° C. (50° F.) in the warmest month, with the temperature of the Cold Caps below 10° C. in the warmest month. This, of course, has a universal application and differs from the bioclimatic system only in the different thermal means used to characterize the limits of the major zones and in the system of thermal constants by which variations are determined to measure the relative intensity of the modifying influences.

Supan's 34 minor divisions (fig. 38) designated as "Climatic Provinces" are, however, not at all comparable with the bioclimatic minor zones, because they are characterized by different combinations of climatic elements, e. g., relative amount and periods of rainfall, direction of prevailing winds, etc. These provinces are, however, more or less directly related to the major climatic types of the major bioclimatic zones and in this sense are in harmony with the bioclimatic system, wherever on any continent they come within the thermal range index of one or more minor zones, or even in some cases where they come within the thermal range indices of two major zones.

The same relation is found between the bioclimatic system and Köppen's classification of climates based on groups of plants under different requirements of heat, cold, rainfall, seasons, etc. He establishes five biological groups, A to E inclusive, in which A agrees in general with major bioclimatic zone III, C with major II, and E with major I, while B and D represent major types related to western, eastern, and central divisions of the continents. B includes plants which require dryness and high temperature of the tropical and lower temperate zone, and D plants which need (or are adapted to) the low mean annual temperatures, cool short summers and long cool winters of major zone I and upper II.

These zones and types of Köppen's system are represented on a sea-level basis by 24 subdivisions or types, which are designated by the names of typical plants, crops, animals, etc., and are related to given thermal means for the coldest or warmest months, months of varying amounts of rainfall, combinations of temperature with rainfall, etc. The vertical distribution of continental types is indicated for elevations to 4,000 meters; and the general relations of pressure, winds, ocean currents, etc., to climatic types are designated by symbol letters and numerals; all this, as shown on a map of the world, represents an ideal distribution

of the major and minor divisions and types and, as a whole, represents one of the most comprehensive systems that has ever been proposed.

While there is a radical difference between Köppen's system and the bioclimatic system as to terminology and characterizing elements, there is a remarkable agreement in principles in that (1) Köppen's zones serve to illustrate certain features of the principle of the bioclimatic zones and zonal types; and (2) a place on any continent coming within the thermal range of a given minor zone will also come within the climatic type indicated on the map by Köppen for that particular region, or at least within the one coming nearest to his specifications.

The agreement between the bioclimatic, Supan's, and Köppen's systems is in the fact that the major and minor bioclimatic zones, as based on the thermal indices alone, serve as a uniform world-wide matrix in which to place the climatic, biologic, seasonal, weather, and other minor type groups of any system, insofar as they meet the general and specific requirements of specialists in climatology, meteorology, geography, or any other science involving a comparative study of problems in geographic distribution.

Some characterizing elements of the minor bioclimatic zones and zonal types are also found in Ravenstein's hygrothermal types of climate based on relative humidity and temperature; Mühry's rainfall types; Köppen's hyetal regions of the world, based on seasonal distribution of rainfall; Herbertson's natural geographic regions and types, based on combinations of temperature, rainfall, seasons, topography, and vegetation; Ward's zones and climatic subdivisions, based on temperature, pressure, humidity, intensity of skylight, weather, etc.; and in other units proposed by different writers who have discussed climates, and especially in Merriam's life zones of North America, as discussed in pages 90 and 93. All of these differ more or less from each other and from the bioclimatic system in terminology, designations of geographical ranges and distribution of major and minor groups, but all agree in the general principles involved, and most of the divisions and subdivisions (under various designations) when interpreted as major and minor types fall into the bioclimatic system of major and minor zones and zonal types.

In the bioclimatic system of zones, the principle of zonal types can be applied in the same way to most of the systems (both old and recent) of geographical distribution and zonation of biological elements and features, such as the comprehensive systems proposed by Sclater, Gunther, Murray, Allen, Wallace, and other zoologists; and Hardy, Herbertson, Schimper, and other botanists and plant geographers. All of these systems differ more or less from each other in the characterizing elements and in the range and limits of their major and minor divisions, but each system is more or less subject to adjustment to the bioclimatic system through the recognition of their divisions as major and minor types of the major and minor bioclimatic zones.

All these many and varied systems, representing the distribution of climates, seasons, plants, and animals of the continents, have been important contributions to knowledge; and all combined make available a comprehensive source of information on the historical features of the subject.

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CLASSIFICATION OF ZONAL TYPES

Since the zonal types are of great value as indices to the bioclimatic character of the minor zone of a place and to the type of farming and type of products best adapted to it, their classification is of special importance (1) in bringing together their characterizing elements under one coordinate system of major and minor groups and divisions in accordance with their general or specific relations to each other and to the system of classification of the bioclimatic zones; (2) in making them available for direct application in analyzing the bioclimatic elements and features of a geographic position; and thus (3) in providing a comprehensive basis for comparative study and specific interpretation.

The general principles involved in the designation and classification of types of zones are: (1) The major and minor physiographic elements represent the true causation-factor complex which everywhere contributes to the variation from the requirements of bioclimatic law, the law of the seasons, and the laws of the zonation of the distinctive features of a region or continent; (2) the major and minor climatic, biologic, and other variable types represent the modified effect of the causation-factor complex types, and therefore may be designated as *response types;* (3) the variations of these response types from their constants are a measure of the relative intensity of the modifying influences; (4) the major physiographic causation types occur as longitudinal regions which may include one or more minor zones, and even all or parts of the three major zones, as in the case of major west-coast, east-coast, conti-

nental, and mountain-physiographic types; and (5) this longitudinal principle applies also to major and some minor climatic and vegetation response types.

TERMINOLOGY

In the development of a terminology for the designation and classification of causation factor and response types an attempt has been made to formulate a coordinate system of symbol letters and numerals to represent major and minor groups of types, with such descriptive or suggestive adjectives as appear most appropriate. Thus roman numerals are adopted for *primary groups;* capital letters for *major groups;* arabic numerals for *minor groups;* small plain letters and numerals for *divisions;* small italic letters for *sections;* and small plain double letters, as *aa*, *ab* to *az*, *ba* to *bz*, etc., for *schedules*, as applied in the following system.

SYSTEM OF CLASSIFICATION OF TYPES OF BIOCLIMATIC ZONES

Primary I. *Primary causation group*, including major geographic and physiographic features of the land and water of the continents.

Major Causation Groups

Major A. *Geographic group*, including the major geographic relations of coastal, continental, and mountain regions of a continent.

Major B. *Physiographic group*, including the major features of high and low land relief, local relation of land and water, general physical features of the soil, and other elements which separately or in various combinations represent stable or constant causation elements in contributing to regional and local modifications of the requirements of the bioclimatic law and other natural laws of effect or response.

Primary II. *Primary response group*, including major groups of responses to, or effects of, the major and minor causation groups in which climate, weather, seasons, and other elements are interpreted as primarily the variable effects of fundamental causes or causation constants, as astronomical, terrestrial, continental, regional, and local.

Major Response Groups

Major C. *Climatic group*, including thermal, humid, arid, wind, weather, and other elements of climate as related to regional and local features of the bioclimatic zones and as representative of zonal types.

Major D. *Weather group*, including relative humidity, rain, dry, evaporation, barometric pressure, clear, cloudy, fog, wind, storm, and other variable elements of weather as applied to local regions and areas of the minor zones as indices of distinctive types of weather.

Major E. *Season group*, including thermal, normal, abnormal, wet, dry, frostless, phenological, and other regional and local features of the modified effects of the terrestrial or physiographic causes as distinguished from astronomical causes.

Major F. *Time group*, including distinctive features of variation from a normal or constant in the dates of the beginning and ending and length of the seasons, as for thermal seasons, thermal sum, phenological, frostless, daytime, etc., which may be expressed in terms of time as indices of regional and local types.

Major G. *Biologic group*, including distinctive regional and local features of the prevailing plants, animals, ecologic associations of a bioclimatic zone as modified by physiographic factor types, and associated with characterizing elements of climate, weather, and season types.

Major H. *Economic group*, including distinctive agricultural, urban, industrial, hygienic, nonhygienic, and other regional and local features as related to the several causation and effect types of the bioclimatic zones.

Primary I

MINOR GROUPS OF MAJORS A AND B

Minor 1. West-coast regions.
Minor 2. Continental or interior regions.
Minor 3. East-coast regions.
Minor 4. Regions of interior seas and large lakes.
Minor 5. Mountain systems.
Minor 6. Local topography.
Minor 7. Human influence.

DIVISIONS AND SECTIONS OF MINORS 1 TO 7

Minors 1, 2, 3, 4. Coast and continental types.
Division a1. Lowland types.
Sections, *a* shore and tidewater, *b* coastal plain, *c* prairie, *d* savanna, *e* valley, *f* ravine, *g* depression, *h* swamp, *i* bog.
Division a2. Highland types.
Sections, *a* hills, *b* hill plateau, *c* low plain, *d* slopes, *e* coves, *f* hill ravines.
Division a3. Soil types.
Sections, *a* wet, *b* dry, *c* sand, *d* clay, *e* lime, *f* acid, *g* warm, *h* cold.
Minor 5. Mountain systems.
Divisions, a1 west, a2 interior, a3 east, a4 longitudinal, a5 latitudinal ranges.
Sections, *a* peak, *b* plateau, *c* plain, *d* slope (n) north, (s) south, (e) east, (w) west, *e* valley, *f* ravine, *g* glacier, *h* snow line, *i* timber line.
Minor 6. Local topographic types.
Division a1. General causes by low and high land features of relief.
Minor 7. Human influence types, including local regions, areas, and places in which the effect of physiographic types has been modified by human agencies.
Division a1. Agriculture.
Division a2. Urban.
Sections, *a* large city, *b* small city or large town, *c* village.
Division a3. Industrial.
Sections, *a* mining, *b* manufacturing, *c* transportation.

Primary II

MINOR GROUPS OF MAJOR C, CLIMATE

Minor 8. Thermal.
Minor 9. Humid or rain.
Minor 10. Arid, dry, or desert.
Minor 11. Wind.
Minor 12. Weather.

DIVISIONS AND SECTIONS OF MINORS 8 TO 12

Minor 8. Thermal types, including division, section, and specific regional and local types of the minor zones as identified by thermal elements alone.
Division a1. Thermal zones and zonal types.

Schedule aa.—*Thermal indices to zones and types*

Zones		*a*	*w*	*c*	*d*	*e*	*f*	*h*	*i*	*j*
I	−1	0.63	34.00	−32.75						
	−2	14.37	44.00	−15.25	25.54	55.70	69.98	−23.30	−3.30	6.00
	−3	25.63	52.50	−1.25	36.80	64.20	80.52	−9.30	10.70	21.50
	−4	33.75	59.00	8.50	44.92	70.70	88.58	.45	20.45	47.00
II	−1	37.50	62.00	13.00	48.67	73.70	92.30	4.95	24.95	59.00
	−2	45.00	68.00	22.00	56.17	79.70	99.50	13.95	33.95	99.00
	−3	48.75	71.00	26.50	59.92	82.70	102.50	18.45	38.45	123.00
	−4	55.00	76.00	34.00	66.17	87.70	107.50	25.95	45.95	171.00
	−5	58.70	78.90	38.50	69.86	90.60	110.40	30.45	50.45	201.00
	−6	65.70	83.90	47.50	76.86	95.60	115.40	39.45	59.45	273.00
	−7	69.85	86.20	53.50	81.01	97.90	117.70	45.45	65.45	321.00
III	−1	75.45	88.60	62.30	86.61	100.30	120.10	54.25	74.25	393.00
	−2	81.56	89.77	73.35	93.81	103.00	122.80	65.95	85.95	501.00
	−3	86.85	89.95	83.75	101.81	106.00	125.80	78.95	98.95	621.00
	−4	89.00	90.00	88.00	105.81	107.50	127.30	85.45	105.45	681.00
App. tables		3	3	3	4	4	4	4	4	5

Explanation of schedule *aa:*
I, II, III major zones: (I) 1 to 4, (II) 1 to 7, (III) 1 to 4 minor zones.
a annual mean index to zonal limits.
w mean of the warmest month zonal type.
c mean of the coldest month zonal type.
d mean maximum for the year zonal type.
e mean maximum for the warmest month zonal type.
f highest or absolute maximum zonal type.
h mean minimum for the coldest month zonal type.
i mean minimum for the year zonal type.
j effective sum zonal type.

Division a2. Lowest recorded temperature types (see appendix schedule 1).
Section *a*. Thermal degrees Fahrenheit.
Schedule ab. −90, −60, −40, −30, −20, −15, −10, −5, 0, +5, 10, 15, 20, 30, 40, 50.
Division a3. Climatic types; major *caw* coastal or mountain type, and *wac* continental type.
Minor 9. Humid, wet or rain types, including regional and local averages for annual and seasonal.
Division a1. Relative humidity types (see major D minor 13, sec. *a*, schedule ac).
Division a2. Relative rainfall or precipitation types (see major D minor 14, secs. *a* to *h*, inclusive).
Minor 10. Arid, dry, and desert types, including regional and local averages of precipitation within a given low range for the year.
Division a1. Dry (see major D, 15, sec. *a*).
Division a2. Semidesert (see major D, 15, sec. *b*).
Division a3. Desert (see major D, 15, sec. *c*).
Minor 11. Wind types, including general characteristic features of the prevailing winds of major regions during the year or given seasons.
Division a1. Trade winds.
Division a2. Monsoon.
Division a3. Westerly wind.
Division a4. Calm or doldrum.
Sections *a* general; *b* periodic.
Division a5. Prevailing direction and character.
Section *a*. Direction, n, s, e, w, ne, nw, se, sw.
Sections *b* dry, *c* moist, *d* hot, *e* cold.
Division a6. Storms.
Sections *a* track, *b* direction (division a5, sec. *a*), *c* frequency 1 to 10 or more in year (see D, 22, division a2, schedule ay), *d* intensity, average miles per hour for the season or year.
Minor 12. Weather, including general average features for the seasons and the year as related to local regions.
Division a1. Changeable.
Sections *a* marked or rapid, *b* moderate or slow, *c* periodic.
Division a2. Stable.
Sections *a* during the year, *b* periodic or seasonal.

MINOR GROUPS OF MAJOR D, WEATHER

(As applied to local areas and places)

Minor 13. Relative humidity.
Minor 14. Rain or precipitation.
Minor 15. Dry or drouth.
Minor 16. Evaporation.
Minor 17. Barometric pressure.
Minor 18. Clear or sunshine.
Minor 19. Cloud.
Minor 20. Fog.
Minor 21. Wind.
Minor 22. Storm.

DIVISIONS AND SECTIONS OF MINORS 13 TO 22

Minor 13. Relative humidity (see appendix schedule 3).
Division a1. Year, season, and month.
Section *a* Schedule ac in percentage, 12, 30, 40, 50, 60, 70, 80, 90.
Minor 14. Precipitation.
Division a1. Rainfall.
Section *a*. Number of days in given month; schedule ad. 0, 3, 6, 9, 12, 15, 18, 21, 24, 27, 30.
Section *b*. Number of days in given season; schedule ae. 0, 10, 20, 30, 40, 50, 60, 70, 80.
Section *c*. Number of days in a given year or average annual; schedule af. 0, 15, 30, 60, 90, 120, 150, 180, 210, 240.
Section *d*. Inches in a given month or average monthly; schedule ag. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.
Section *e*. Inches in a given season or average seasonal; schedule ah. 0, 3, 6, 9, 12, 15.
Section *f*. Inches in a given year or average annual (see appendix schedule 3); schedule ai. 2, 7, 13, 17, 25, 35, 45, 55, 65, 75, 85, 95, 100.
Section *g*. Month or months of greatest rainfall and amount in inches (see appendix schedule 3); schedule aj. Ja, Fe, Ma, Ap, My, Jn, Jl, Ag, Sp, Oc, Nv, Dc.
Section *h*. Month or months of least rainfall and amount in inches (see appendix schedule 3); schedule ak (same as aj).

Minor 15. Dry or drouth, semidesert and desert types.
Division a1. Drouth.
Section *a*. By month, months or seasons, dates and periods.
Section *b*. Subdesert, rainfall less than 15 inches in year.
Section *c*. Desert, rainfall less than 5 inches in year.
Minor 16. Evaporation types.
Division a1. Amount in a given or average year, season, or month; schedule al. 0, 4, 8, 16, 24, 32, 40, 48, 56, 64, 72, 80, 88, 96, 104, 112 inches.
Minor 17. Barometric pressure types.
Division a1. Year, season, month, relative to temperature or period of days; schedule am. 27.5, 28, 28.5, 29, 29.5, 30, 30.5 inches.
Minor 18. Clear day types.
Division a1. Number in month; schedule an. 0, 3, 6, 9, 12, 15, 18, 21, 24, 27 days.
Division a2. Number in season; schedule ao. 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80 days.
Division a3. Number in year and average; schedule ap. 0, 10, 30, 50, 70, 90, 110, 130, 150, 170, 190, 210, 230, 250, 280, 300 days.
Division a4. Percentage or tenths of sky clear, day or date, month, season or year; schedule aq. 20, 30, 40, 50, 60, 70, 80, 90 percent, or schedule ar. 2, 3, 4, 5, 6, 7, 8, 9 tenths.
Minor 19. Cloudy day types.
Division a1. Number in month; schedule as. 0, 3, 6, 9, 12, 15, 18, 21, 24, 27 days.
Division a2. Number in season; schedule at. 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80 days.
Division a3. Number in year or average year; schedule au. 0, 10, 30, 50, 70, 90, 110, 130, 150, 170, 190, 210, 230, 250, 280, 300 days.
Division a4. Percentage or tenths of sky cloudy, day or date, month, season or year; schedule av. 20, 30, 40, 50, 60, 70, 80, 90 percent, or schedule aw. 2, 3, 4, 5, 6, 7, 8, 9 tenths.
Minor 20. Fog.
Division a1. Day time.
Division a2. Night time.
Schedule ax. percentage, 25, 50, 75, 100 of each or both.
Division a3. Number of days in month, season or year, by schedules as, at, and au in minor 19.
Minor 21. Wind types (see major C minor 11 divisions a1 to a5).
Minor 22. Storm types, local.
Division a1. Prevailing direction, from N, S, E, W, NE, NW, SE, SW.
Division a2. Frequency by month, season or year.
Schedule ay, number 0, 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 40, 50.
Division a3. Intensity.
Sections *a* hurricane, *b* tornado, *c* typhoon, *d* cyclone.
Schedule az, number in year, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.
Division a4. Velocity, miles per hour.
Schedule ba. 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 120, 140, 150.
Division a5. Thunderstorms, number in month, season or year.
Schedule bb. 0, 2, 4, 6, 8, 10, 15, 20, 25, 30, 35, 40, 50.
Division a6. Snowstorms, schedule bb.
Division a7. Sleet storms, schedule bb.

MINOR GROUPS OF MAJOR E, SEASONS

Minor 23. Thermal indices to beginning and ending, and periods.
Minor 24. Normal with little variation from the average or constant.
Minor 25. Abnormal, more of less wide range of variation from the average or constant.
Minor 26. Wet, months or seasons.
Minor 27. Dry, months or seasons.
Minor 28. Frostless season without killing frosts.
Minor 29. Phenological.

DIVISIONS AND SECTIONS OF MINORS 23 TO 29

Minor 23. Thermal indices.
Division a1. Monthly mean indices (see appendix schedule 2).

SCHEDULE bc.—*Thermal means indices for the beginning of the seasons*

Latitude	Thermal indices in degrees Farenbeit			
	Spring	Summer	Autumn	Winter
Above 60	35			35
60 to 57	40	55	55	40
57 to 51	43	60	60	41
51 to 27	45	*Interior* 64 or 66	64	43
57 to 27	40 or 43	*West coast* 53, 55 or 60	53, 55 or 60	43

Minor 24. Normal types.
Division a1. Spring, 1 or *Sp.*
Division a2. Summer, 2 or *Su.*
Division a3. Autumn, 3 or *Au.*
Division a4. Winter, 4 or *Wi.*
Minor 25. Abnormal types (same divisions as in 24).
Minor 26. Wet seasonal types.
Division a1. General in all seasons.
Division a2. Periodic by seasons or months.
Schedule bd, months, 1 to 12, or January to December.
Schedule be, seasons, 1 to 4, or *Sp, Su, Au, Wi.*
Minor 27. Dry season types.
Division a1. General in all seasons.
Division a2. Periodic by seasons or months, as in 26 schedules bd and be.
Minor 28. Frostless season or period types (see appendix table 6).
Division a1. By names and number of months without frost.
Schedule bf, 0 to 12 months, January to December inclusive (see major F, 33, schedule bk).
Minor 29. Phenological seasonal types, and length of seasons, based on dates for beginning of seasons (see appendix table 9).
Division a1. Dates earlier or
Division a2. Dates later.
Schedule bg, 10, 15, 20, 25, 30, 35, 40, 45 days.
Division a3. Season shorter or
Division a4. Season longer.
Schedule bh, 10, 20, 30, 40, 50, 60, 70 days.

MINOR GROUPS OF MAJOR F, TIME

Minor 30. Thermal seasons.
Minor 31. Thermal sum seasons.
Minor 32. Phenological, plants and animals.
Minor 33. Frost.
Minor 34. Daytime.

DIVISIONS AND SECTIONS OF MINORS 30 to 34

Minor 30. Seasons by thermal indices for dates and periods in days relative to minor 23 schedule bc.
Minor 31. Thermal Sum (see appendix table 5).

Minor 30. Schedule bi. Date and period constants												Minor 31
Zones		Spring		Summer		Autumn		Winter		Warm		Schedule bj
Ma	*Mi*	*md*	*per*	*md*	*per*	*md*	*per*	*md*	*per*	*per*		*Sum period*
I	−2	July 29		(Winter)				July 29	365	0		0
	−3	June 24		(Spring-autumn)				Aug. 23	305	60		60
	−4	May 28		(Spring-autumn)				Sept. 12	258	107		107
II	−1	May 15	69	July 23	12	Aug. 4	49	Sept. 22	235	130		130
	−2	Apr. 21	68	June 28	61	Aug. 28	49	Oct. 16	187	178		178
	−3	Apr. 8	68	June 15	85	Sept. 8	49	Oct. 27	163	202		202
	−4	Mar. 19	67	May 25	128	Sept. 30	47	Nov. 16	123	242		242
	−5	Mar. 7	65	May 11	155	Oct. 13	45	Nov. 27	100	265		265
	−6	Feb. 11	32	Mar. 15	258	Nov. 28	22	Dec. 20	53	312		312
	−7	Jan. 26	11	Feb. 6	325	Dec. 28	7	Jan. 4	22	343		343
III	.1			Jan. 14	365	Jan. 14			0	365		365
App. tables		9		9		9		9		9		5

Minor 32. Phenologic types with unlimited divisions, sections and specific distinction.
Division a1. Plant.
Sections *a*. Indigenous, *b*. introduced species and varieties, each with its distinctive seasonal events and periods, as hickories, oaks, etc., wheat, oats, corn, etc., seeding and harvest dates and periods of development, with types represented by relative variations from schedules or tables of constants.
Division a2. Animal.
Sections *a*. Indigenous, *b*. introduced, under the same principle as plants in division a1.
Minor 33. Frost dates and period types (see appendix table 6).

SCHEDULE bk.—*Frost dates and period constants*

Zones		Spring	Autumn	Frostless
Ma	*Mi*	*md*	*md*	*per*
I	+.4	July 24	July 24	0
	−4	July 5	Aug. 12	38
II	−1	June 23	Aug. 24	62
	−2	May 28	Sept. 17	112
	−3	May 13	Sept. 29	139
	−4	Apr. 18	Oct. 19	184
	−5	Apr. 3	Oct. 31	211
	−6	Feb. 25	Nov. 24	272
	−7	Jan. 24	Dec. 10	320
III	.1	Dec. 31	Dec. 31	365

Minor 34. Day time types in 12-hour units and percentage of total units between the equinoxes and solstices (see appendix schedule 5).

SCHEDULE bl.—*Sums of 12-hour units and percentage of day*

Zones		North latitude	1 spring		2 summer		3 autumn		4 winter	
Ma	*Mi*		*dt*	Per-cent	*dt*	Per-cent	*dt*	Per-cent	*dt*	Per-cent
I	−3	66.46	143	76.8	144	77.4	52	28.2	51	28.6
	−4	60.00	125	67.2	126	67.7	64	35.5	63	35.3
II	−1	57.00	121	65.0	121	65.0	68	37.7	66	37.0
	−2	51.00	115	61.8	115	61.8	72	40.0	71	39.8
	−3	48.00	113	60.7	113	60.7	74	41.1	73	41.0
	−4	43.00	110	59.1	110	59.1	77	42.7	76	42.6
	−5	40.00	109	58.6	109	58.6	78	43.3	77	43.2
	−6	34.00	105	56.4	105	56.4	81	45.0	80	44.9
	−7	30.00	103	55.3	103	55.3	82	45.5	81	45.5
III	.1	27.00	102	54.8	102	54.8	*Lat* 83	46.1	82	46.0
	.4	3.00 S.	93	50.0	93	50.0	3N 90	50.0	89	50.0
	.1	27.00	86	46.2	86	46.2	99	55.0	98	55.0
II	−7	30.00	85	45.6	85	45.6	100	55.5	99	55.6
	−6	34.00	83	44.6	83	44.6	102	56.6	101	56.7
	−5	40.00	81	43.5	81	43.5	104	57.7	103	57.8
	−4	43.00	79	42.4	79	42.6	106	58.8	105	58.9
	−3	48.00	76	40.8	76	40.8	109	60.5	108	60.6
	−2	51.00	74	39.7	74	39.7	111	61.6	110	61.7
	−1	57.00	69	37.0	69	37.0	117	65.0	116	65.1
I	−4	60.00	66	35.4	65	35.4	121	67.2	120	67.4
	−3	66.46	53	28.4	53	28.4	137	76.1	137	76.9
		Soutb	1 autumn		2 winter		3 spring		4 summer	
Totals			186		186		180		178	

SCHEDULE bl.—*Sums of 12-hour units and percentage of day*—Continued

	Hours		
	24	12	12
North			
1 spring, March equinox to June solstice	93	186	----
2 summer, June solstice to September equinox	93	186	372
3 autumn, September equinox to December solstice	90	180	----
4 winter, December solstice to March equinox	89	178	358
South			
3 spring, September equinox to December solstice	90	180	----
4 summer, December solstice to March equinox	89	178	358
1 autumn, March equinox to June solstice	93	186	----
2 winter, June solstice to September equinox	93	186	372

MINOR GROUPS OF MAJOR G, BIOLOGIC

Minor 35. Plant.
Minor 36. Animal.
Minor 37. Ecologic.

DIVISIONS AND SECTIONS OF MINORS 35 TO 37

Minor 35. Plant types, general.
- Division a1. Tundra types of major zone I.
- Division a2. Desert types of major zones I, II, III.
- Division a3. Grass types of major zones I, II, III.
- Division a4. Shrub types of major zones II, III.
- Division a5. Tree or forest types of major zones II, III.
  - All with innumerable sections and specific types as distinguished by presence or absence of characterizing species and groups of species.

Minor 36. Animal types.
- Divisions a1 to a5 same as in minor 35.

Minor 37. Ecologic types, including distinctive local associations and interrelations in minor 35 or 36, or of both plants and animals with a great many divisions, sections, and specific types to be designated by ecologists.

MINOR GROUPS OF MAJOR H, ECONOMIC

Minor 38. Agricultural and rural.
Minor 39. Hygienic (healthy).
Minor 40. Nonhygienic (unhealthy).

DIVISIONS AND SECTIONS OF MINORS 38 TO 40

Minor 38. Agricultural types.
- Division a1. Grazing or grass culture, with sections relative to kinds of animals and grass crops.
- Division a2. Cereal crops, with sections for each.
- Division a3. Mixed grazing and cultivated crops or other special crop types with innumerable sections and specific types.
- Division a4. Irrigation, relative to types of agriculture.
- Division a5. Forestry and silviculture types.

Minor 39. Hygienic types with many divisions, sections, and specific types relative to needs and requirements for the health of man based on experience and interpretation.

Minor 40. Nonhygienic with many divisions, sections and specific types relative to distinctive features and effects of unhealthy conditions based on experience and interpretation.

THE SYSTEM OF CLASSIFICATION

In this system of major and minor groups, divisions, sections, and schedules to specific zonal types, the primary group I majors A and B represent geographic and physiographic causation types, which on most of the continents, and especially on North and South America, occur as longitudinal west coast, east coast, west mountain, east mountain, interior or continental, basin, plains, and similar regions, extending in a general poleward direction from the Equator, while the general trend of bioclimatic zones on a sea-level basis is from southeast to northwest across the continents parallel to the trend of the bioclimatic isophanes. These major geographic and physiographic causation types are characterized by major bioclimatic effect or response types, in that the general type of climate and general types of vegetation may extend across two or more minor zones.

While the major groups of bioclimatic types may extend across the minor zones, there is, however, always a more or less distinctive gradation in characterizing features or elements from one minor zone to the next above and below it, by which each gradation may be distinguished as a zonal type, so that each major physiographic type is characterized by many distinctive bioclimatic elements within any given minor zone across a continent. Thus each of the minor groups 1 to 5 of the major causation groups A and B and each of the minor response groups 8 to 12 of major C (climate) and of minor groups 35 to 37 of major G (biologic) apply in general to all of the major and minor bioclimatic zones as do also majors D, E, F, and H. These major and minor *effect types* of the causation types apply not only to the minor zones and zonal sections but also within them to general and local regions, local areas, and geographic positions down to specific places of a few square rods or even feet, wherever a division, section, or specific response type is clearly distinguished by one or more of its characterizing elements.

GEOGRAPHIC AND PHYSIOGRAPHIC CAUSATION TYPES

The causation groups and types of primary I, major A and B, include the distinctive stable or constant physical features of the land and the geographic distribution of such features in any continental or insular area. It is in these major features that we find the elements of the minor causation complex, which to a greater or less degree tend to modify the effects of the major complex. Thus the major causation groups and the minor and division types (down to the specific character of the soil of an immediate place) serve to modify certain elements and features of the climate, weather, seasons, and consequently the biologic and climatic elements.

The physiographic elements and types are determined by observations, reference to published descriptions, maps, etc., and are analyzed and interpreted for regions and places as a basis of interpreting the causes of given effects. For example, in minor group 7, human influence, the divisions *a1* agriculture, *a2* urban, and *a3* industrial, represent local factor types. In division *a1* the factor types come under the influences of artificial modifications, as by clearing the land of original vegetation, cultivation of crops, drainage, irrigation, etc.

In division *a2* the factor types come under the modifying influences of cities, towns, and villages, and their immediate environs. These urban types include many features of modified climatic, weather, and season elements which distinguish them from the rural types. Especially is this to be noted in the modified temperature, the dates of killing frosts, the frostless seasons, and the relative lengths of the seasons of the year as based on thermal and phenological indices. In this respect cities or towns are to be classed in the physiographic factor complex in that they affect the local bioclimatic elements.

As with other types there is, in addition to size and relative effects, a very wide range of variation in the urban types of the tropical, temperate, arctic, and alpine regions. Moreover, each city or town constitutes a

specific type so far as effects are involved, because no two are alike in situation and combination of other zonal types or in industries, transportation, etc.

The feature of these urban factor types of immediate interest and importance in bioclimatics is the fact that, as a rule, they represent record positions for climatic and meteorological data, which are always somewhat modified, and thus differ more or less from the same group of data recorded in the rural districts just outside the range of the influence of the city. Notwithstanding, such modified data have served as the principal basis for conclusions on subjects of research and practice in agriculture, and will continue to do so until some radical changes are made in the location of record stations.

In division *a3*, the industrial factor types are represented by mining, manufacturing, transportation, etc., which tend to modify natural factors and thus represent local elements of the physiographic group, as did also pioneer agriculture in clearing and plowing the land, irrigating, etc. Mining operations and the use or manufacture of mined products are factor types of the minor zones because they disturb (and often to a marked extent) one or more of the natural features. Smoke and fumes which are injurious to vegetation; acids, etc., which pollute streams and kill aquatic life; the manufacture of forest products that modify local factors; and artificial lakes for the production of power are all examples of industrial factor types.

Transportation is also a factor type so far as natural conditions are disturbed and modified by the construction and operation of railroads, canals, highways, etc., with consequent effects on plants, animals, and related economic practices.

Irrigation on an extensive scale is a factor type in artificial reservoirs, canals, and in changes from arid to humid conditions of the soil; each and all contribute to the modification of local elements.

It is to be kept in mind that while physiographic, climatic, weather, and other types may extend through many minor and even through the major zones, the effect is different in each minor zone as represented by temperature and time elements and by specific biological and economic elements.

CLIMATIC TYPES OF MAJOR C

Climatic types include and represent the major and minor effects of the modifying influences of the causation types, in which temperature is the most important. The schedule of thermal indices, minor 8, division *a1*, schedule *aa*, represents the requirements of bioclimatic law as related to the standard major and minor zonal constants of appendix tables 3, 4, and 5.

The most significant and important feature of this schedule and its application is the relation of the *w* and *c* records to the *a* record, because the various combinations not only indicate the relation of the *w* and *c* types to the *a* zone as to relative higher or lower equivalents, but what is more important they indicate at once the minor physiographic and minor climatic type that are represented by the record position, as shown in examples 59, 73, etc.

Thus, when the *c* type is higher and the *w* type is lower than the *a* zone, it is designated as a *caw* climatic type of a coastal or mountain physiographic type, and when the *w* type is higher and the *c* is lower than the *a* zone it is designated as a *wac* climatic or continental type, and when all three come within the same minor zone with little or no variation from the constants it is designated as a normal climatic type, or when both *c* and *w* are below or above the *a* zone they are designated as abnormal or transition climatic types.

Thermal types *d* to *i* are of less importance but in the complete analysis of the thermal types of a record position (examples 54, 55, 56, and 73) they are important type indices. As with the *w* and *c* types the significance of the *d* to *f*, *h* and *i* types are in the variations of the records from their constants and the relations of these types and variations to the *a* zone and *w* and *c* types and variations, as it is also in the relation of any one to the others.

The effective sum (*j*) type is represented by the constants of appendix table 5 which is of interest in showing the relative sum of the monthly mean temperatures of the warm period of the year at record positions and its relation to the *a* zone and to the different thermal types, the seasons, season types, etc., as shown in examples 54, 55, 56, 73.

In division *a2* of minor 8, schedule *ab*, the lowest record temperature types are given from −90° to +50° F. to indicate the type. These types do not conform to the requirements of bioclimatic law but represent a special variable effect relative to regional and local physiographic types. They are of special importance as indices or measures of the relative intensity of a special influence at widely separate or nearby record positions, as is forcibly brought out in example 71, which shows that the record (−37) at Kanawha Farms in latitude 39.25°, altitude 600 feet, is 11° colder than at St. Paul Island, Alaska, in latitude 57.25° at or near sea level in Behring Sea which is 18° farther north. It is also shown that it is 10° colder at Kanawha Farms than at Parkersburg, W. Va., and 15° colder than at Marietta, Ohio, within 10 to 20 miles. The significance of this great difference in nearby lowest temperature types is in the fact that certain hardy shrubs are killed or seriously damaged at Kanawha Farms in severe winters, while they are only slightly damaged at Parkersburg or Marietta. The physiographic factors in this case are the small enclosed frost pocket valley of a small river and open country types at Kanawha Farms, and the urban type of Parkersburg and Marietta.

Climatic minor 9, including divisions *a1* relative humidity, and *a2* rain types apply to average climatic elements for local regions as distinguished from weather elements of local areas and places.

Climatic minor 10, including divisions *a1* dry, *a2* semidesert, and *a3* desert, apply in the same way to regions rather than to local areas, and in both of these minor types (9 and 10) the divisions are distinguished by relative amounts of average humidity, with temperature and rainfall according to the corresponding schedules for the weather types.

Climatic minor 11 includes divisions and section types as distinguished by the average character, direction, and relative intensity of the winds during the months, seasons, or year as designated by descriptive names or by schedule letters or numerals.

Climatic minor 12 includes divisions and sections distinguished by general features of the weather of a general or local region for a period of years as distinct from the variable local features of the weather.

WEATHER TYPES OF MAJOR D

The weather types as distinguished from climatic types, represent the effect of major and minor physiographic factors as related more specifically to (*a*) the geographic position or place and (*b*) to time. *In all variable nature there is perhaps nothing more variable*

than the weather at any given place, especially within the minor zones of major II. Thus the more specific weather types as distinguished from the general climatic types (C, 12) necessarily must be associated with the local area and record position for each year, as a basis of comparison with those of preceding periods or years, or with the average.

The elements of the weather, other than temperature and time, are not manifested in accordance with any principle of the bioclimatic law (or other laws) and are not, therefore, subject to interpretation under the principle of the constant and variable. These features are, however, subject to interpretation and comparison, under the principle of index schedules by representative symbol quantities, etc., and thus are of special importance in analyzing the weather types of a place.

Minors 14 and 15 include the most important of the weather types for vegetation, agriculture, and human interests in general, because without rain or irrigation no useful plants can be produced; so that of all the climatic and weather elements water is next to light and proper temperature in its importance for life and human progress.

As with other elements of weather, the time, frequency, and quantity of rainfall is exceedingly variable in different regions, areas, and places within the same bioclimatic minor zone; and it is in this variation that precipitation types are distinguished and their relative importance determined as elements of the weather type complex of a place. Thus the minor weather types, 13 to 22, with their divisions, sections, and schedules give a comprehensive system of indices for the determination of the specific type or type-complex for any record position on any continent so far as records of the given elements are available.

SEASON TYPES OF MAJOR E

This major group of terrestrial season types represents the major and minor modifications of astronomic and astroterrestrial seasons by the major relations and distribution of the land and water of the world, and by the major and minor physiographic features of the land, as fully discussed in pages 77–78.

In minor 23, the thermal types of the seasons, like those of climate, are the most important of this major group as related to the bioclimatic zones because of the availability of distinctive thermal characterizations of the types by standard daily or monthly mean indices for the beginning and ending of the seasonal periods at any record position.

In minor 24, the normal season types are given. These are in general agreement with the requirements of the law of the seasons and the bioclimatic law, as represented by the range of difference in the variation of the recorded elements from their constants.

In minor 25, the abnormal season types are represented by wide variations of the recorded elements from their corresponding constants.

In minor 26, the wet season types for the year, season, or month are characterized by the average precipitation, with variations from year to year within a given range of the schedules *bd* and *be*, and also minor 14 schedules *ad* to *ak* inclusive, which apply to this group.

In minor 27, the dry season types represent deficiency of rainfall in all seasons and in periods by season or month, with annual variations within the range of the quantities of the schedules in minor 26.

In minor 28, the frostless season types are of special economic importance to the horticulturist and grower of tender crops. They are easily determined by the grower for his immediate locality by records from year to year. An average is found to correspond with a number in the schedule (major F, 33, *bk*); then by noting the variations from this average his practice can be regulated so as to provide for a minimum loss. There is a wide variation in the months and length of the season between nearby places and, of course, a great difference between higher and lower minor zones, ranging from no months in major zone I to twelve months in major zone III. (See explanation of appendix tables 5, 6, 9, and 16.)

In minor 29, the phenological season types include general earlier, later, shorter, or longer seasons relative to the position date constants, as distinguished from the more specific time types in major F. They are determined in schedules *bg* and *bh* by the observed and recorded dates of seasonal events of individual (or groups of) species and varieties of plants.

TIME TYPES OF MAJOR F

This major group of time types of the minor zones, as distinguished from major climatic, weather, and season types, is based on dates and periods of days relative to standard tables of time, thermal, and distance constants of the bioclimatic law and such time schedules of elements as are more or less independent of this or other laws.

The dates of beginning and ending and length in days in minor 30, thermal season, and the types in minor 31, thermal sum seasons, are of special significance and importance as related to human interests and needs, as has been previously discussed.

In schedules *bi* and *bj* the combined constants are based on appendix table 9, seasons date constants, and 5 thermal sum period constants, and apply to the lower limit constants of the major and minor bioclimatic zones on a sea-level basis. They thus represent the range for the lower zone in each case, as for spring between May 28 for lower 4 of major I and May 15 for lower 1 of major II in minor 1, so that the monthly mean, or an index event for the beginning of spring at any place coming within this zonal range, represents the spring season type of the zone for the place. This same principle and method applies to summer, autumn, winter, and to the thermal sum season. (See examples 71 and 75.)

Thus the date constants of table 9 for the beginning of the seasons serve as a basis for (1) finding the season date constants for any geographic position, and wherever records are available the variations from the requirement constant; and (2) interpreting the seasons for the positions. It is in this higher or lower relation of the zonal type of a given position zone that we find the significant features of all zonal types, because it is in the variation from the type constant for a zone that is found the index to the relative character and intensity of the modifying factors.

In minor 32, the phenological types, division *a1* includes those characterized by dates of specific events of plants in the progress of the seasons and to the best time for certain seasonal duties in agricultural practice, while division *a2* includes dates of seasonal events of animals.

As has been determined and demonstrated, no two species or no two varieties of a species respond as to

date of the same event in exactly the same way to the same local factor complex; and as a rule the exact date on which a given event occurs cannot be detected and recorded. It has been found, however, that *of all the elements of climate, weather, and seasons, the average date of a seasonal event is the most reliable index to the phenological type,* because a seasonal event in the vital activity of a plant or animal is the ultimate observable and measurable effect of all of the local causes and factors or the causation-factor complex. It is, therefore, the true index to the phenological type, and in turn the type is the true index to the relative modification of the minor zone as expressed in its local characteristics.

Because of variations in responses to the same complex and to different complexes, there is practically no limit in number or range from general to specific phenological types. Each species and each distinct variety, and to a certain extent each individual represents a response type. There is also an unlimited range of application of phenological type indices in research and practice, but in bioclimatics we need to consider only the general types and principles involved.

In the application of minor 33, in schedule *bk* (appendix table 6), any average record frost date or period coming within the range of a given zonal constant represents the frost type for the record position. Thus the same principle and significant features are covered as in the types of minors 30 and 31, in that *the variation of the record type from the type constant is an index to the relative character and intensity of the cause.*

In schedule *bl* of minor 34, the sums and percentage of daytime units are based on figure 29, appendix schedule 5, and table 15. These daytime types represent the unmodified effect of purely astronomic causes as related to the astroterrestrial seasons. Thus they are constants of the astronomic law of the seasons and are practically invariable as to time and place, in that all geographic positions at the same latitude have for a given equinoctial period the same sum of daytime, and nighttime and the same percentage, regardless of the physiographic features of the surface of the earth. In other words, the zonal constant for a position may be middle 4 of major II, while the record zone may be middle 3 or middle 5; or minor 6 of major II may be represented at the base of a mountain and minor 4 of major I at the summit, but the sum of daytime units and percentage will remain the same for all positions and zones in a given latitude.

It is in this principle that the significance of the daytime type is found because the amount of daylight is an important factor in the vital activities of plants and animals. Thus, while the record effect would be the same in the same zone and zonal types in the same latitude, the record zone and the climatic, season, and biologic types are never exactly the same at all positions in the same latitude and altitude, due primarily to the difference in the causation-factor complex. Moreover, differences in altitude within the same latitude may cause a very wide range of difference in the period or time of plant and animal activity, owing to the differences in the sums of daytime.

BIOLOGIC TYPES OF MAJOR G

This group includes three distinctive minor groups and a large number of divisions, sections, and specific types based on the various characteristics of plants and animals, as modified by the major physiographic types of regions and minor factor types of local areas.

Minor 35, plant and vegetation types, includes groups of plants which are primarily adapted to the different physiographic division types of major zones I, II, and III.

It is to be kept in mind that the vegetation types represent the immediate or ultimate effect of the regional and local environment, which if known serves as an index to the plant type that may be expected, and conversely the known plant types serve as an index to the type of environment as represented by the ecological association, since *like causes produce like effects.*

While this principle does not imply that the same species will be found in the same zonal type of a given minor zone on all continents, or even on the same continent, it does signify that very different species will conform to certain general and special requirement types of adaptation which serve to identify their relation to a given zone and zonal type. In other words, a designated plant or animal type of a given minor bioclimatic zone on different continents is not necessarily characterized by the same species or even by the same genera, but may be characterized by related or unrelated species of a similar type with similar adaptations, habits, and appearances.

In minor 37, the ecological types are characterized by associations of plants or animals. They differ from the plant and animal types only in their more specific relation to local environment, with particular reference to the interrelation, associations, successions, and climaxes of the biologic elements as they are analyzed and designated by ecologists.

In many respects the ecological types of a given minor zone are of special scientific interest and economic importance. Within its proper limits, ecology renders a service of special value to students in most branches of biology, wherever a problem involves a consideration of the interrelated factors and effects of local environment.

The ecologic types of the zones as distinguished by plant and animal elements, like those of plant and animal types, are not subject to interpretation under the principle of the constant and variable of the bioclimatic law. They are, however, intimately related to climate, weather, season, and time types, which are determined and interpreted under the principles of the bioclimatic and other laws of effect.

Thus the guides to the preliminary identification of ecological types may be found in the bioclimatic principles and methods, by beginning with the fundamental physiographic factor types of the local area and following with the identification of the local climate, weather, season, time, and biologic types. Then in connection with the published data it will be a comparatively simple matter to interpret the ecological type or types of a given minor zone or zonal type.

The terminology for ecological types and the development of a system of classification to coordinate with the general system of bioclimatic types must be left to the ecologist. In the meantime, however, such terms as are now in use by ecologists for designating distinctive associations should be applied so far as they will define and convey the idea of a zonal type. The intimate association of ecological types with the physiographic, climatic, and other zonal types will suggest additional terms, symbols, etc., to distinguish their coordinate relations to the minor zones, zonal sections, and zonal types.

ECONOMIC TYPES OF MAJOR H

This group of zonal types includes such natural biologic types of minors 35 and 36 as have been modified by human influence and are related to human interests and needs, with particular reference to agriculture and related industries, human health, recreation, etc.

In minor 38 the agriculture and rural types relate to rural or pastoral divisions, sections, and specific types, which include such features of agricultural practice as are best coordinated with physiographic, climatic, weather, season, and other types of the minor zones.

In division *a1* the grazing types include general and local regions and local areas within the limits of a given minor zone which naturally or as modified are best adapted to some one or more types of animal husbandry which depend more on grazing than they do on grain and other cultivated forage crops. There are naturally many general and specific types, such as reindeer types of the tundra regions, range types of the plains, steppes, and prairie, cattle, sheep, dairy, and similar types, as there are also types adapted to mixed animal husbandry, each within its minor zone as characterized and distinguished by its peculiar physiographic, climatic, weather, and seasonal features, in addition to the kinds of domestic animals which are evidently best adapted to it.

The significance of these agricultural types is in their service as guides to the best utilization of occupied or unoccupied land of a given zonal type. In division *a2*, the cereal and other cultivated crop types include general and local regions and local areas which are utilized, or on account of given combinations of zonal types may be best utilized for food and other crops. Here again there may be recognized and designated as many specific types as there are distinctive types of products. The more important types are intimately related to zonal types to which a specific crop or group of crops is best adapted, as demonstrated in practice and as interpreted from other available evidence.

In division *a3* the mixed grazing and crop types include regions and areas which on account of special combinations of conditions are best suited to mixed farming.

In division *a4* the irrigation types are of special interest and importance relative to major and minor types of different major and minor arid types of zones, because the kinds of crops, types of agriculture, and success in practice will be governed largely by the minor zone, its major climatic and season types, types of native plants and animals, and the physiographic features including the type of soil. Thus, while there is necessarily a wide range of irrigation types from the Tropics to the poleward limits of agriculture, those of each minor zone will be characterized by some general or specific feature to which, for the best results, a given type of agriculture is adapted.

In division *a5* the forestry and silvicultural types include both natural and planted forest growth which is best adapted to given minor zones and zonal types. The natural types are of special importance as indices to the tree species to be selected for planting either from native or foreign sources of supplies of seeds or plants, because, as a rule, the types of species found to succeed best in a given minor bioclimatic zone and type will serve as reliable indices to the zone and type of the same continent or of other continents from which seeds or plants of desirable species may be introduced with the best prospects of success.

In minor 39, the hygienic types include zonal types of the greatest importance to human health. They are variously represented by places with a combination of factor and effect types which contribute to better health or to the prevention or cure of specific diseases. They are first identified by historical effects, as experienced and recorded at established health resorts. Then places with little or no record experience are compared with established health types on the assumption that like types will give like results.

In minor 40, the nonhygienic types include places which are (or are likely to be) detrimental to human health and progress. While types of this character may occur in any minor zone, due to one or more factors of the physiographic or effect types, they are more prevalent in lowland types of the minor zones of major III, largely because of the prevalence of disease carrying insects and other agencies, some of which are subject to control, but also because of unfavorable conditions of climate, weather, and other elements, which are not subject to control.

APPLICATION

In the application of the principles involved in this bioclimatic system of zonal types, the object is to determine the types of a given record position and local and general regions. The methods of procedure are (1) to analyze the causation-factor types of a place, from their major down to their local and specific elements, as the basis for study and interpretation of the bioclimatic complex and adaptations; and (2) to determine from the position records, tables of constants, and schedules (*a*) the general character of the local cause and factor types and the number and character of the response types; (*b*) the minor zonal types represented; (*c*) the variations of the record elements from their corresponding constants, schedules, or averages; and (*d*) to utilize the variations as a basis for interpreting the response types for nonrecord positions.

CONCLUSIONS

In a review of the preceding system of classification of zonal types it is to be kept in mind (1) that the significance of the zonal type is not so much in a given specific type, or in a group of types, as it is in the type-complex as related to given problems as analyzed from the major and minor physiographic factor types down through the major and minor climatic, weather, season, and other effect types, and (2) that each problem involves a consideration and study of the various combinations of the elements of two or more types in order to have a sound basis for correct interpretations and conclusions.

Under the bioclimatic system and method it is in the records of a local area or region that the true key is to be found to the identification of the zonal type complex of a specific record position, or of the types which may be expected to occur at nonrecord positions within the local or general region, because it is the record position which represents the minor zone and zonal types.

Thus in accordance with a fundamental principle in bioclimatics, *a bioclimatic problem is primarily related to the geographic position*, and *secondarily to the local area, the minor zone, the zonal type, and the local region.*

GRAPHIC REPRESENTATION OF ZONAL DISTRIBUTION OF LIFE AND CLIMATE

In graphic representations of the different concepts of the zonal distribution of life and climate of the world, the following maps of the major and minor zones are intended merely as general representations of the principles and laws involved.

ASTRONOMIC ZONES

Figure 34 illustrates the astronomic concept of uniform belts around the world over the land and water. I represents the north and south frigid, polar, or arctic zones; II, the north and south temperate or intermediate zones; and III the torrid or tropical zones.

These zones plainly represent the requirement constants of an astronomic law of equal biologic and climatic phenomena along the parallels of latitude with no modification for the influences of land and water.

ISOTHERM ZONES

The concept of major thermal (isotherm) zones is that of latitude ranges based on specific sea-level isotherms. This concept is a decided advance over that of the astronomic zones because it provides for irregular belts around the earth as the effect of oceanic and continental influences, which modify the major effects of purely astronomic causes.

This thermal principle or law, as recognized by Supan and others, agrees with the astronomic law in that it is based on a uniform level of land and water and thus does not provide for the profound modifications produced by elevations of the land above this common level.

Figure 35 is based on Supan's temperature zones (as given in Bartholomew's Physical Atlas, vol. III, Meteorology, pl. I). The heat equator (*a*) is represented by the isotherm of maximum mean annual temperature; the hot belt (*b–b*) is bounded on the north and south by the isotherms representing the mean annual temperature of 20° C. (68° F.); the temperate belts (*b–c*) lie between these lines and the isotherm of 10° C. (50° F.) for the warmest month; and the cold caps (*c*) cover the regions around the poles to the isotherm 10° C. (50° F.) for the warmest month.

ISOPHANE ZONES

Figure 36 represents the principle of the sea-level isophane constants in defining the range and limits of the major zonal constants as in table 3 and example 50 for the Northern and Southern Hemispheres: (*a*) Gives the equatorial isophane 0 to represent the annual mean constant of 89° F.; (*b*) gives colimit isophane 30 east and west, and north and south, between major zones II and III, as represented by the annual mean constant of 69.85° F.; (*c*) the colimit isophane 60 between major zones I and II north and south, as represented by the annual mean constant of 33.75° F.; and (*d, d*) the polar limits (not represented on the map) are the north and south polar isophanes 90, as represented by the annual mean constant of −6.25° F. The extension of colimit lines across the oceans is merely to represent connections between eastern and western isophanes of the same number. (See pt. 1, pp. 13 and 19.)

BIOCLIMATIC ZONES

Figure 37 illustrates the major bioclimatic zones of the continents as modified by major physiographic features of the land and as represented by the record annual means referred to table 3. The isophane and bioclimatic concept differs from the astronomic and isothermal concepts in showing the unequal range, limits, and distribution of the major zones as they are modified by the elevation of the land and other physiographic factors.

Thus arctic major I occupies the north polar region with very irregular equatorward limits ranging from about latitude 70° in northwestern North America and Eurasia to about latitude 60° on the eastern coasts, while the north and south arctic-alpine of major I ranges from just above the northern sea-level limit southward over the snow-covered mountains of the continents of the Northern and Southern Hemispheres. It will be noted that the continental areas of the Northern Hemisphere are occupied by major zone II, while a relatively small part of the Southern Hemisphere is occupied by it. Major zone III north and south of the Equator is much smaller than major II north, with the greater part north of the Equator in Africa and India and the greater part south in South America and Australia. The sea-level range of this zone comes between about latitude 30° north and 30° south, with an extension to near latitude 40° in Australia.

The bioclimatic method of mapping the major zones applies also to the interpretation and mapping of the limits and distribution of minor zones; but it is in the interpretation of the minor zones, zonal sections, and zonal types for any specific position represented by meteorological and biological records that the bioclimatic method will render its greatest service.

BIOCLIMATIC ZONES AND CLIMATIC PROVINCES

Figure 38 illustrates the general relations between the major bioclimatic zones of figure 37 and Supan's 34 climatic provinces, in which the provinces may be interpreted as divisions of the minor zones or as major types of the major zones.

Thus it will be noted that province 1 agrees closely with bioclimatic major zone I, while provinces 2 to 9, 11 in Eurasia, 23 to 27, and part of 28 in North America come in bioclimatic major zone II. Provinces 14 and 15 in South Africa, 18 and 19 in Australia, and 31 to 34 in South America come in major II south, while bioclimatic major III north and south is represented on the eastern continents by provinces 10, 12, 13, 16, 17, and 21, and on the western continents by 28, 29, 30, and part of 31.

A study of this figure shows that while Supan's climatic provinces have a general relation to the major zones on a sea-level basis they have little direct relation to the zones when altitude is considered. Thus provinces 2 to 8 east and 23 to 26 and 29 to 34 west include by latitude the two major zones I and II north and south of major III, and vertically all three major zones from sea level to the summits of the higher mountains.

As to the minor zones and provinces there is often a difference so great in the regions covered that there are scarcely any recognizable relations, unless one considers the provinces as climatic types to include two or more minor zones.

Thus, while climatic provinces serve their purpose in the study and interpretation of the distribution of distinctive climatic complexes and major and minor zonal types, they do not serve any direct purpose in the identification of the bioclimatic zones and their limits.

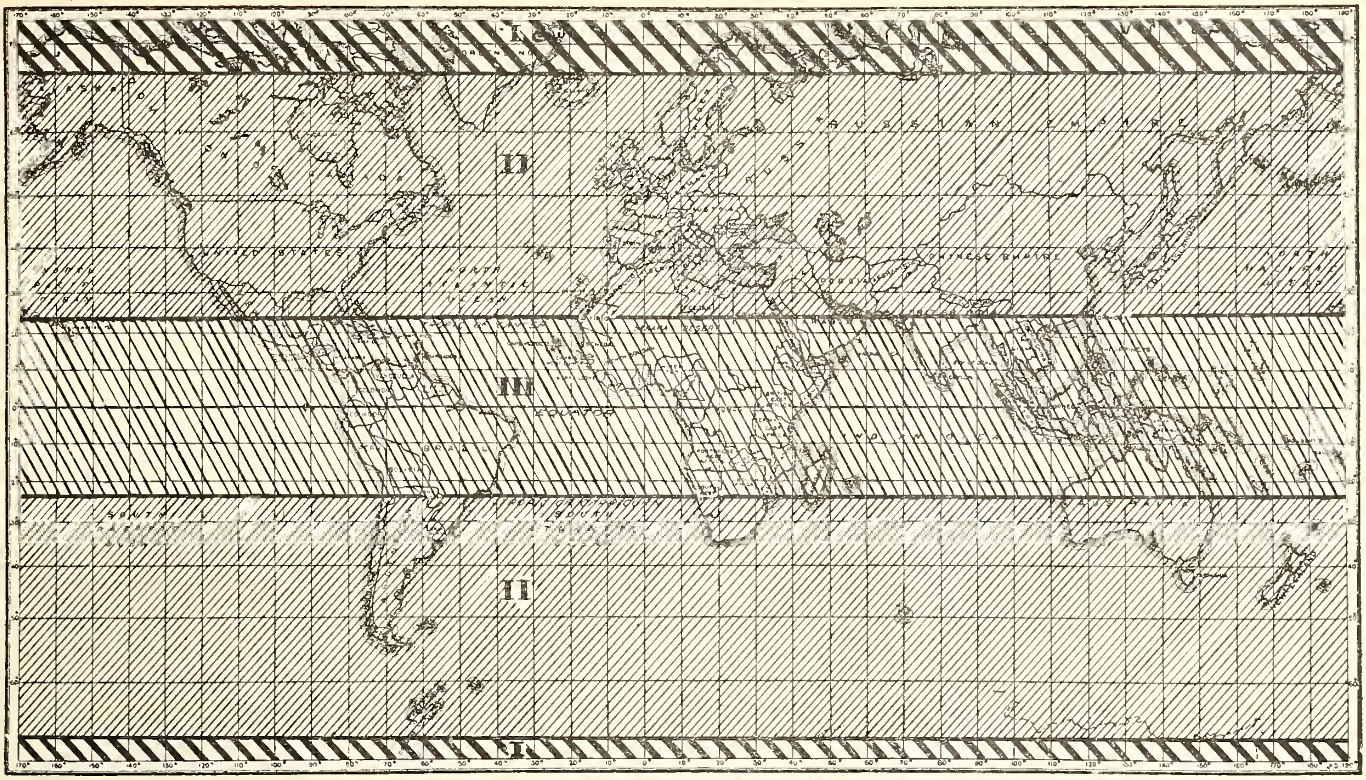


FIGURE 34.—Astronomic zones of the world.

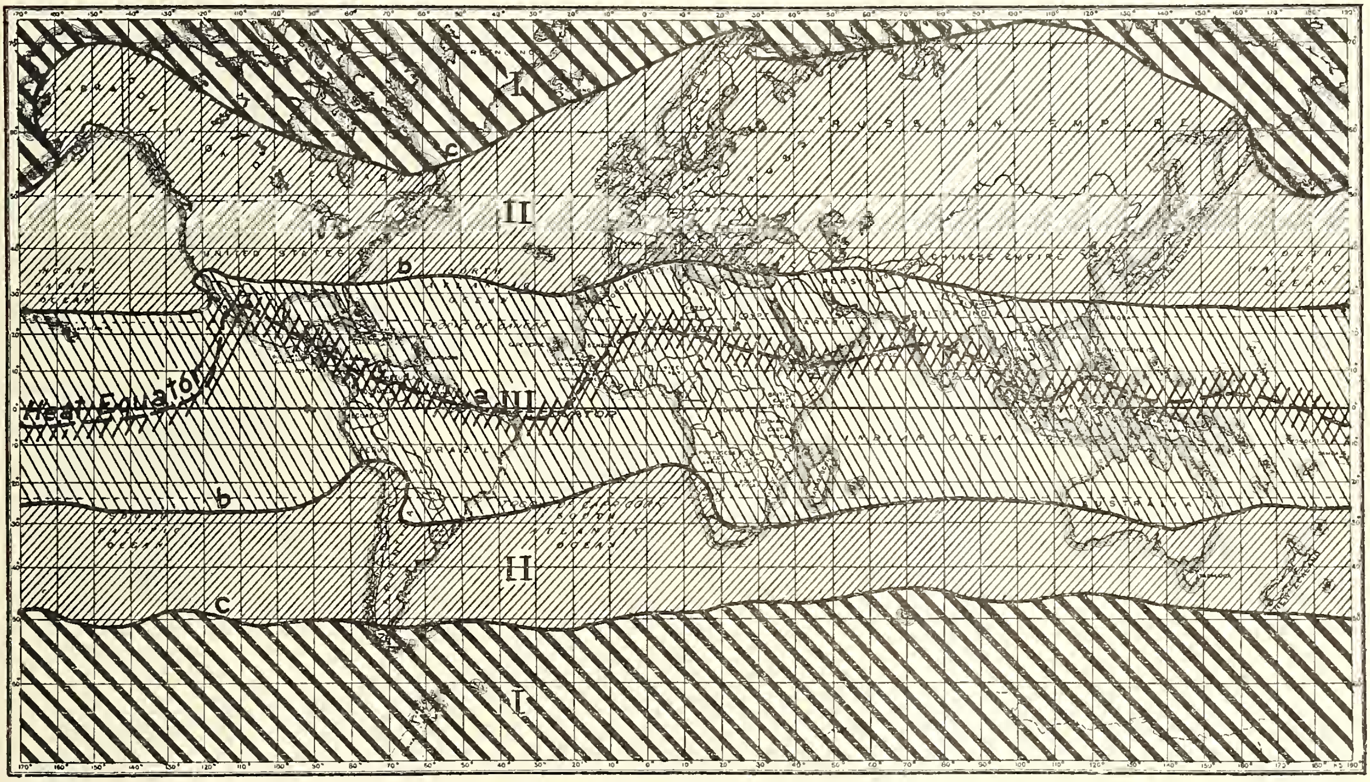


FIGURE 35.—Supan's temperature zones of the world.

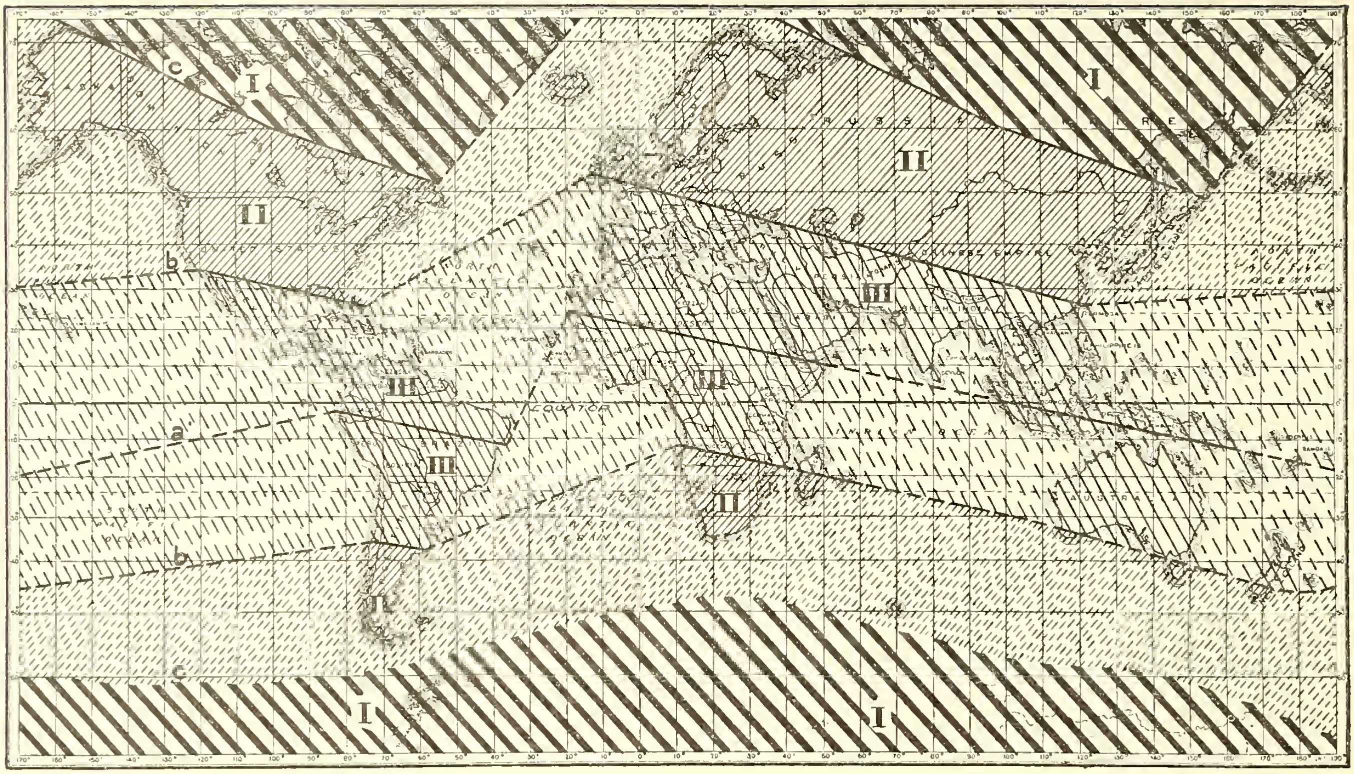


FIGURE 36.—Sea-level isophane zones of the continents and oceans.

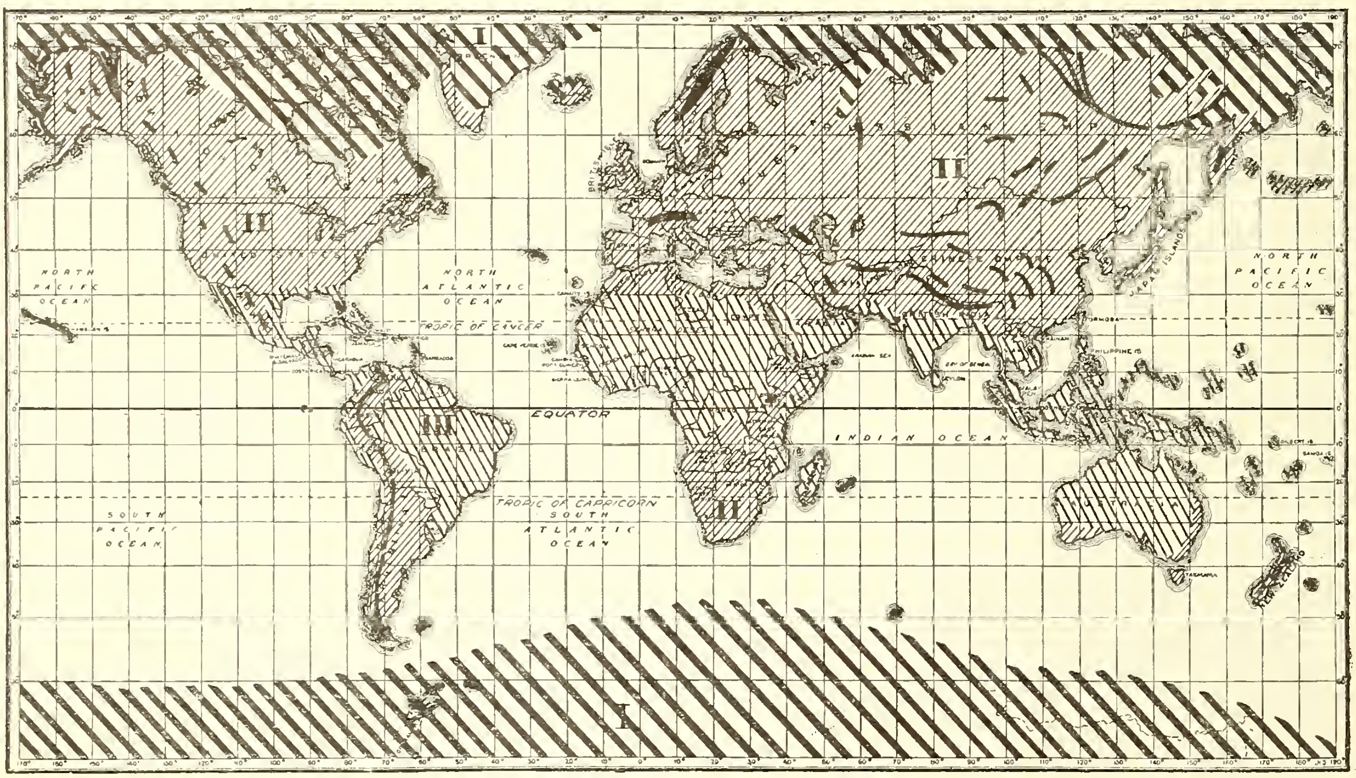


FIGURE 37.—Bioclimatic zones of the continents.

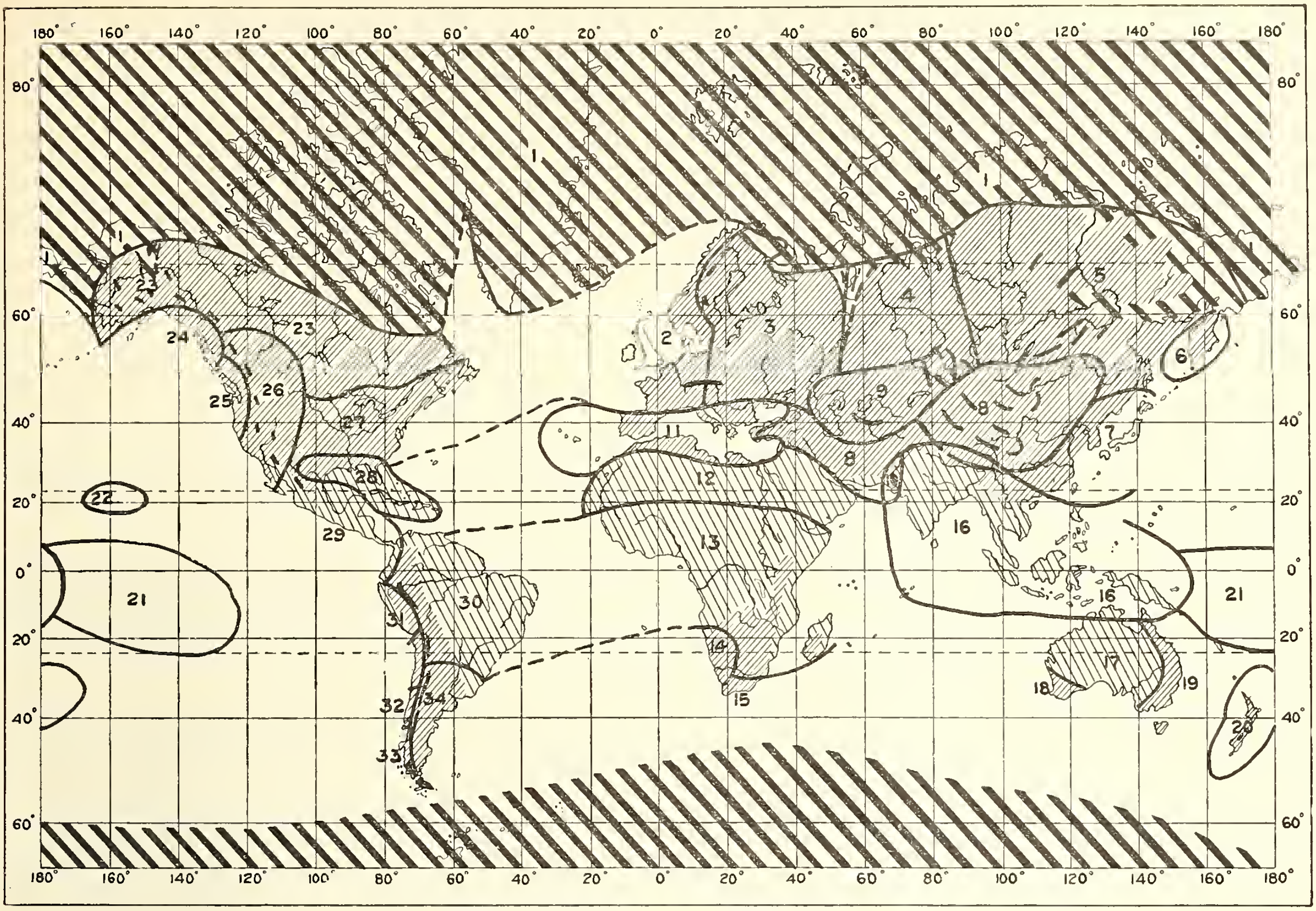


FIGURE 38.—Bioclimaitc zones and Supan's 34 climatic provinces.

The same principle holds in the relations between major bioclimatic zones and the many other different systems of regions, provinces, etc., that have been proposed by different writers from different climatic, botanical, and zoological points of view. All of these systems differ from each other and from the system of the bioclimatic zones; but when the elements of the various systems are interpreted as representing different categories of major and minor *zonal types* all can be related to certain fundamental principles of the bioclimatic law and the law of the zonation of life and climate.

GENERAL APPLICATION OF THE LAWS AND PRINCIPLES OF BIOCLIMATIC ZONES AND ZONAL TYPES

The basic methods of applying the principles of bioclimatics to the interpretation of zones and zonal types differ only in detail and specific purpose from those already outlined and illustrated. The methods of procedure are also similar to those already outlined. First, the record positions under consideration are listed by number and name, giving for each the geographic coordinates latitude, longitude, isophane, and altitude, followed by the latitude equivalent in degrees to feet of the position altitude; this plus the position isophane gives the isophane equivalent to the altitude; and finally the records are listed for each position.

With this list of basic data, the zones and types represented at each position are determined by referring the record to the corresponding constant in a table of constants, which gives the record isophane in the isophane column and the record zone or type in the scale of zonal constants.

Then *ri* compared with *ei* gives the *lv* latitude variations of the records from their constants. This variation is an index to, and measure of, the relative intensity of the modifying influences within the local area and is utilized to interpret the zones or types for nonrecord positions, as shown in example 51 for the Lafayette, Ind., quadrant.

EXAMPLE 51.—*Preliminary interpretation of the a zones and w and c zonal types for nonrecord positions in the Lafayette, Ind., quadrant*

Limits	*pi*	*pa*	200	400	600	700	800	900	1,000
		le	0.50	1.00	1.50	1.75	2.00	2.25	2.50
		ei	44.00	44.50	45.00	45.25	45.50	45.75	46.00
		a lv	+1.75	+1.75	+1.75	+1.75	+1.75	+1.75	+1.75
		a ix	45.75	46.25	46.75	47.00	47.25	47.50	47.75
		a z	II .4	.4	+.4	+.4	+4	+4	+4
Upper	43.50	*w lv*	−0.50	−0.50	−0.50	−0.50	−0.50	−0.50	−0.50
		w ix	43.50	44.00	44.50	44.75	45.00	45.25	45.50
		w zt	II −4	−.4	.4	.4	.4	.4	.4
		c lv	+4.00	+4.00	+4.00	+4.00	+4.00	+4.00	+4.00
		c ix	48.00	48.50	49.00	49.25	49.50	49.75	50.00
		c zt	II−3+4	−.3	.3	.3	.3	.3	+.3
		ei	43.00	43.50	44.00	44.25	44.50	44.75	45.00
		a lv	+1.75	+1.75	+1.75	+1.75	+1.75	+1.75	+1.75
		a ix	44.75	45.25	45.75	46.00	46.25	46.50	46.75
		a z	II .4	.4	.4	.4	.4	+.4	+.4
Lower	42.50	*w lv*	−0.50	−0.50	−0.50	−.50	−.50	−.50	−0.50
		w ix	42.50	43.00	43.50	43.75	44.00	44.25	44.50
		w zt	II +5	−4+5	−4	−.4	−.4	−.4	.4
		c lv	+4.00	+4.00	+4.00	+4.00	+4.00	+4.00	+4.00
		c ix	47.00	47.50	48.00	48.25	48.50	48.75	49.00
		c zt	II +.4	+4	−3+4	−3	−.3	−.3	.3

This example shows the method of finding the *ix* isophane index, the minor *a* zone, and the *zt* minor *w* and *c* zonal types for the nonrecord positions of the upper and lower isophane limits of the quadrant, with *pa* from 200 to 1,000 feet, which gives the *le* latitude equivalents. Thus *pi* plus *le* equals *ei*, which plus the *a lv* latitude variation gives the *a ix*, which in table 3 gives the interpreted *a* zone for the nonrecord positions. In a like manner *ei* minus *w lv* 0.50 gives *w ix* and the interpreted *w zt* zonal types, and *ei* plus *c lv* 4.00 gives the *c ix* and the interpreted *c zt* zonal type. It will be seen that the indicated *a* zones for the seven nonrecord altitude positions on isophane 43.50 are from major II minor middle (.) 4 to upper (+) 4; the *w* types from lower (—) 4 to middle (.) 4; and the *c* types from lower (—) 3 upper (+) 4 to upper middle (+.) 3. For isophane 42.50 the *a* zones range from .4 to +.4, the *w* types from +5 to .4, and the *c* types from +.4 to .3.

This method as applied to the border isophanes applies alike to any intervening 0.25° isophane of the quadrant. Since the zones for the record position, Lafayette, isophane 43, altitude 600 feet, are *a* zone .4, *w* type —.4 and the *c* type —.3, this position is in fact representative of the quadrant.

The average altitude for the seven positions within this quadrant with an average altitude of 700 feet gives *a* variation +1.00 and zone .4, *w* variation —1.00 and type —.4, and *c* variation +3.25 and type +4, all of which shows that the records and variations of a single representative position within a local region will serve to indicate the *a* zone and *w* and *c* types to be expected at all positions within it. Thus by this method of procedure the thermal zones and zonal types can be interpreted for any nonrecord position within an area or region, but it is preferable to utilize the average variation for a number of record positions within a given area or quadrant as the index to nonrecord positions within it.

INTERPRETATION OF ZONAL TYPES BY TIME SUBJECTS

The utilization of date and period records and variations from their constants for the interpretation of time types for record and nonrecord positions may be illustrated by winter-wheat seeding and harvest dates, and the period in days from seeding to harvest.

Thus taking as an example the average record dates and period for Marshall County, Ill., of example 1, the *S*, *H*, and *P* zonal types for nonrecord altitude positions on isophane 43.25 are interpreted as in example 52.

Example 52.—*Interpretation of winter wheat seeding, harvest, and period zonal types for Marshall County, Ill., and nonrecord positions*

SECTION A. MARSHALL COUNTY, ILL.

No.	Geographic coordinates				Equivalents		Seeding		Harvest		Per day
	pl	*plo*	*pa*	*pi*	*le*	*ei*	*md*	*yd*	*md*	*yd*	
9	41.00°	89	700	43.25	1.75	45.00	Sept. 15	258	July 1	182	289

SECTION B. INTERPRETED VARIATIONS AND ZONAL TYPES BY AVERAGE RECORDS FROM TABLE 7

Subjects	*ei*	*pc*	*pr*	*dv*	*ri*	*ZC*	*zt*
S seeding	45.00	270	258	—12	48.00	II .4	II—3+4
H harvest	45.00	176	182	+6	46.50		+.4
P period	45.00	271	289	+18	47.25		+4

Example 52.—*Interpretation of winter wheat seeding, harvest, and period zonal types for Marshall County, Ill., and nonrecord positions*—Continued

SECTION C. INTERPRETED ZONAL TYPES FOR NONRECORD POSITIONS

pi	*pa*	400	500	600	700	800	900	1,000
43.25	*le*	1.00	1.25	1.50	1.75	2.00	2.25	2.50
	ei	44.25	44.50	44.75	45.00	45.25	45.50	45.75
	S pc	273	272	271	270	269	268	267
	S dv	—12	—12	—12	—12	—12	—12	—12
	S id	261	260	259	258	257	256	255
	S zt	II +4	+4	+4	—3+4	—3	—.3	—.3
	H pc	173	174	175	176	177	178	179
	H dv	+6	+6	+6	+6	+6	+6	+6
	H id	179	180	181	182	183	184	185
	H zt	II .4	.4	.4	+.4	+.4	+.4	+4
	P pc	265	267	269	271	273	275	277
	P dv	+18	+18	+18	+18	+18	+18	+18
	P id	283	285	287	289	291	293	295
	P zt	II +.4	+.4	+.4	+4	+4	+4	—3+4

In section A of this example the average geographic coordinates are given for the county with the averages of the record seeding and harvest dates and the period in days between dates.

In section B are given *ei* the equivalent isophane, *pc* the position constant in table 7, *pr* the record seeding and harvest year-dates and the period in days, with *dv* the variation in days, *ri* the record isophane, *ZC* the zonal constant by *ei*, and *zt* the record zonal types by *ri*.

In section C is given for the nonrecord positions on the *pi* position isophane, *pa* the position altitudes 400 to 1,000 feet, and *le* the latitude equivalents for each *pa*, which plus *pi* gives the *ei* equivalent isophanes, followed in each altitude column by *S pc* the seeding date constant, *S dv* the day variation of *pr* from *pc* in section B, *S id* the interpreted date, and *S zt* the seeding-date zonal type for the position altitude, followed by *H pc*, *dv*, *id*, and *zt* for harvest dates, and *P pc*, *dv*, *id*, and *zt* for the interpreted periods.

Thus the zonal types for the nonrecord positions by the seeding-date range from major II +4 to —.3; by harvest date from .4 to +4; and by the period from +.4 to —3+4; all this may be considered as fairly representative of the zonal types for the county within the given range of altitude on isophane 43.25, and shows how the types for the same or any altitude can be interpreted for any 0.25° isophane across the county.

Example 53.—*Analysis of the physiographic and bioclimatic types for Lafayette, Ind.*

Geographic coordinates				Equivalents		*ZC*	*az*
pl	*plo*	*pa*	*pi*	*le*	*ei*		
40.25°	86	600	43.00	1.50	44.50	II .4	II .4

Subjects	Types				
	Ma	*Mi*	*Div*	*Sec*	*Sch*
1. Causation groups:					
A. Geographic, continental, interior.	A	2			
Lowland, prairie (till plains).			a1	*c*	
Soil, clay, warm (alluvial).			a3	*d, g*	
B. Physiographic	B				
Local topography, undulating relief.		6	a1		
Human influence		7			
Agriculture			a1		
Urban, city			a2	*b*	22,000.
Industrial:					
Mining			a3	*a*	Coal.
Manufacturing				*b*	
Transportation				*c*	

EXAMPLE 53.—*Analysis of the physiographic and bioclimatic types for Lafayette, Ind.*—Continued

Subjects	Types				
	Ma	*Mi*	*Div*	*Sec*	*Sch*
II. Effect groups:					
C. Climate	C				
Thermal (see example 54)		8			
Lowest record or absolute minimum.			a2	*a*	*g*—33° F.
Climatic type, continental.			a3		+*w*—*ac*.
Humid		9			
Relative humidity, year. (See D 13)					
Precipitation: (See D 14)					
Wind:					
Prevailing direction, year.		11	a5	*a*	sw.
Hot in summer, cold in winter.				*d, e*	
Storms:					
Direction			a6	*b*	s, sw.
Frequency in year.				*c*	15.
Intensity year (miles per hour).				*d*	50.
Weather, changeable, marked.		12	a1	*a*	
D. Weather	D				
Relative humidity, year		13	a1	*a*	60 percent.
Precipitation		14	a1		
Number of days in seasons.				*b*	*Sp*. 30. *Su*. 20. *Au*. 20.
Number of days in year.				*c*	120.
Inches in seasons				*e*	*Sp*. 12. *Su*. 12. *Au*. 9.
Inches in year				*f*	39.01.
Month of greatest				*g*	May, 4.36 in.
Month of least				*h*	Feb., 2.52 in.
Evaporation, April to September.		16	a1		32 in.
Barometric pressure, year.		17	a1		30 in.
Clear day		18			
Number in seasons			a2		*Sp* 30. *Su* 20. *Au* 40.
Number in year			a3		130.
Percent of sky clear, year.			a4		50 percent.
Cloudy day		19			
Number in seasons			a2		*Sp* 30. *Su* 20. *Au* 40.
Number in year			a3		130.
Percent of sky cloudy, year.			a4		50 percent.
Fog, number of days in year.		20	a3		10.
Wind. (See major C minor 11.)					
Storms		22			
Thunderstorms, number in year.			a5		40.
Snowstorms, number in year.			a6		10.
Sleet storms, number in year.			a7		4.
E. Seasons	E				
Thermal (see example 54)		23			
Normal		24	a1 a2 a3 a4		*Sp*. *Su*. *Au*. *Wi*.
Frostless (see example 54).		28			
Phenological:					
Days earlier		29	a1		*Su* 10. *Wi* 3.
Days later			a2		*Sp* 7.
Seasons shorter			a3		*Sp* 16. *Au* 3. *P* 10.
Seasons longer			a4		*Su* 9. *Wi* 10.
F. Time (see example 54)	F				
Thermal		30			
Thermal sum		31			
Phenological		32			
Frost		33			
Daytime		34			
G. Biologic	G				
Plants		35	a3 a5		Grass. Oak-hickory.
Animal		36	a3		Grazing.
Ecological		37			Grass, oak, hickory.
H. Economic	H				
Agricultural		38	a3		Mixed farming.
Hygienic		39			
Nonhygienic		40			

Example 53 shows how a record position is analyzed into its primary, major, minor, division, section, etc., types by the index elements of the standard type classification. Thus the position is analyzed into 2 primary, 8 major, 30 minor, 39 division, 25 section, and 55 specific or schedule types—a total of 159 type elements. Data given in example 53 are illustrative only, some of the figures presented being assumed instead of being actual records. In a continuation of this analysis to include the thermal, time, astronomic, phenological, seasons, and winter-wheat elements of the tables of constants, 29 additional types are included, as in example 54, the principle, elements, and methods of which are the same as those which have been so often repeated in tables and test examples.

EXAMPLE 54.—*Zone and zonal types represented by records in tables of constants*

Position		Geographic coordinates				Equivalents		*ZC*
Name	State	*pl*	*plo*	*pa*	*pi*	*le*	*ei*	
Lafayette	Indiana	40.25°	86	600	43.00	1.50	44.50	II .4

Sym.	Subjects	*pr*	table	*ri*	zone
	Thermal:	°*F*.			
a	Annual mean	51.0	3	46.25	II .4
					zt
w	Warmest month mean	74.9	3	44.00	II −.4
c	Coldest month mean	25.6	3	48.50	−.3
ct	Climatic type				+*w*−*ac*
d	Mean maximum for year	61.4	4	46.75	+.4
e	Mean maximum warmest month	85.9	4	44.75	.4
f	Highest record	105.0	4	45.50	.4
h	Mean minimum coldest month	17.6	4	48.50	−.3
i	Mean minimum for year	41.1	4	46.25	.4
j	Effective sum, 43° F	149.9	5	45.00	.4
	Thermal and time:	*yd*			
S	Spring frost	115	6	44.50	.4
A	Autumn frost	282	6	45.50	.4
Sp	Thermal index, spring	91	9	46.25	.4
Su	Thermal index, summer	143	9	42.50	+5
Au	Thermal index, autumn	266	9	44.50	.4
Wi	Thermal index, winter	311	9	45.25	.4
		Days			
P	Warm period (thermal)	220	9	45.75	.4
jp	Effective sum period	220	5	45.75	.4
p	Frostless period	167	6	45.00	.4
	Phenological seasons: [1]	*yd*			
Sp	Phenological, spring	91	9	46.25	.4
Su	Phenological, summer	143	9	42.50	+5
Au	Phenological, autumn	266	9	44.50	.4
Wi	Phenological, winter	311	9	45.25	.4
		Days			
P	Warm period (phenological)	220	9	45.75	.4
	Winter wheat:	*yd*			
S	Seeding	258	7	48.00	−3+4
H	Harvest	182	7	46.50	+.4
		Days			
P	Period	289	7	47.25	+4
	Astronomical:	*Units*			
	Daytime, March to September equinox	218	15		
	Nighttime, March to September equinox	154	15		
y	Percent day time, March to September equinox	*Percent* 58.6	(2)		

[1] Based on thermal seasons.
[2] Schedule 5.

The outstanding and significant features of a bioclimatic analysis of a geographic position as in these examples are in showing (1) how *any record position on any continent may be analyzed for comparison on a coordinate basis with such an analysis of any other position;* and (2) how (in example 54) the *a*, *w*, and *c* records alone, or even the *a* record alone, may serve as reliable indices of the zone that may be expected to be represented by the other thermal indices and by the time and phenological indices, because for Lafayette the *a* zone for this position closely represents the zonal types as determined by all of the other thermal indices. While this close agreement may not be found at many other positions, it shows the value of the *a* mean as an index to the local zone.

A much larger number of subjects might be utilized to interpret minor and local types, but for preliminary interpretations this is by no means necessary or even desirable. In fact it is found by many tests that the annual, warm, and cold means, together with physiographic features and types are often sufficient for this purpose. Moreover, in a vast majority of cases the thermal *a*, *w*, and *c* records, and in many the *a* thermal record alone, are the only available thermal data on which to base preliminary interpretations.

With the zones and types interpreted for representative record positions of local areas, regions, or quadrants across a continent, and with interpretations for representative nonrecord positions for ranges in altitude within each local region, a general picture may be presented of the zones and types that may be expected to occur in each region or across a country or continent.

REPRESENTATION OF PRELIMINARY AND SPECIFIC INTERPRETATIONS

There are several methods of representing the zones and zonal types, but the tabular and graphic methods are the most effective.

The Tabular Method

In the tabular method one makes a list of the geographic positions involved in a given study or discussion giving for direct comparison the interpreted minor zones and zonal types for each, as in examples 55 and 56. For long lists it is best to give the zones and types after the name of the position on the same line from left to right with the symbols of the subjects on the upper line as in example 55, while for short lists it is best to give the zones and types under the position numbers for each subject as in example 56.

It will be noted in example 55 that the record zones and types for position 6B, General Base Area, give the same minor zone (.4) and zonal types for all subjects, thus representing the normal zone and types for comparison with those of the other positions, all of which are on or near the same sea-level isophane but have a wide range in longitude and altitude. The close agreement of zones and types of position 5 with those of the General Base Area indicates that at the same level (600 feet) practically the same zones and types may be expected to prevail on the base isophane across Ohio, Indiana, and Illinois, while for the mountains and coasts there is a wide range in the *a* zones and *w* and *c* zonal types.

Example 55.—*Method of tabulating zones and zonal types for long lists of record positions*

Positions			Subject symbols, zones and zonal types												
No.	Name	State	*a*	*w*	*c*	*d*	*e*	*f*	*h*	*i*	*j*	*S*	*A*	*p*	*ct*
2	Tatoosh Island	Washington	II −3	I .4	II +.6	II .2	I .3	I .4	II −.6	II −.4	II +.2	II +.7	III +1	II .7	caw
3	Buffalo	Wyoming	−.3	II −3	+4	+.4	II .4	II −.4	−2	+3	−.2	−2	II −2	−2	cwa
5	Lafayette	Indiana	.4	−.4	−.3	+.4	.4	.4	−.3	.4	.4	.4	.4	.4	wac
6B	General base area	West Virginia	.4	.4	.4	.4	.4	.4	.4	.4	.4	.4	.4	.4	awc
7	Terra Alta	do	.4	−.3	.4	+.4	.3	.2	+4	+.4	−3+4	+4	−3+4	+4	caw
10	Cape May City	New Jersey	−.4	.4	−4	−.3	−2	+3	+5	+.5	.4	.5	.6	+6	caw

Example 56.—*Method of tabulating zones and zonal types for short lists of record positions*

Sym.	Subjects	Position numbers, zones and zonal types					
		2	3	5	6B	7	10
a	Annual mean	II −3	II −.3	II .4	II .4	II .4	II− .4
w	Warmest month mean	I .4	−3	−.4	.4	−.3	.4
c	Coldest month mean	II +.6	+4	−.3	.4	.4	−4
d	Mean maximum for year	.2	+.4	+.4	.4	+.4	−.3
e	mean maximum warmest month.	I .3	.4	.4	.4	.3	−2
f	Highest record	I .4	−.4	.4	.4	.2	+3
h	Mean minimum coldest month.	II −.6	−2	−.3	.4	+4	+5
i	Mean minimum for year	−.4	+3	.4	.4	+.4	+.5
j	Effective sum	+.2	−.2	.4	.4	−3+4	.4
S	Spring frost	+.7	−2	.4	.4	+4	.5
A	Autumn frost	III +1	−2	.4	.4	−3+4	.6
p	Frostless period	II .7	−2	.4	.4	+4	+6
ct	Climatic type	caw	cwa	wac	awc	caw	caw

The Graphic Method

The graphic method includes the map and profile methods. The common method of representing zones, provinces, regions, etc., is by colors or crosshatch on an outline map. This method has many, and often very serious, limitations except on topographic maps of a quadrant or small political division, because an ordinary outline map of a major political division or continent usually is misleading as to the zone represented by a local area or place. The same is true of a map to show the minor zones, because usually there are isolated islands of one zone within the given borders of another, due to some local modification too small to be represented on the map. In fact it *has been this failure to show these island zones on published zonal maps* (e. g., Merriam's zones of North America and the United States) *which has contributed to obstructive criticism of, and prejudice against, the zonal principle as heretofore presented.*

The profile method is especially adapted to the representation of the altitude range and limits of the minor zones and types of a mountain, or across a mountain range, above a given isophane or parallel of latitude. A reliable topographic map also is essential to the correct interpretation and proper presentation of zonal limits by the profile or map method, because it gives not only the elevation but also certain physiographic features and thus serves as a guide to certain modifications in the zonal limits that may be expected; and when topographic sheets are accompanied by soil survey maps they are of special value as indices to economic and other types that may be expected to occur within restricted areas or at specific places (figs. 39 and 43).

It is important to keep in mind (1) that the bioclimatic zones and types refer to terrestrial areas; (2) that the terminology for the major and minor zones and zonal sections by numerical and other symbols are for convenience in application in any language; (3) that this symbolic designation does not prevent the use of old names for the major climate and life zones, provinces, etc., of literature or the application of local names to minor zones for a country or continent; (4) that the classification is intended to represent a comprehensive coordinate system as a fundamental basis for comparative reference study and application; (5) that the minor zones for record positions are interpreted from, and based on, record data, and that for nonrecord positions interpretations are based on the variations

at record positions as applied to the position constant of nonrecord positions within the same zone of influence; (6) that further and more specific interpretation is based on available published or other evidence of the major and minor physiographic, climatic, weather, biologic, season, and economic types represented; (7) *that there are no sharp lines of distinction between two major or minor zones, sections or types of zones*, and thus there is always a more or less wide range of allowable error in the preliminary interpretations of limiting factors or elements of distinction as represented in tables, maps, or graphs; (8) that in addition to the minor zones interpreted by the *a* annual mean index *the bioclimatic zones are not characterized by any single climatic or biologic element*, but rather by prevailing groups or associations and averages of elements, or by an element complex, which, as such, do not extend across a given transition area between the designated minor zones; (9) that modifying factors are usually so general in their influence as represented by recognizable effects that a difference in one or even two degrees of distance in latitude at the same level, or a vertical distance of 400 to 800 feet is often necessary to determine the isophane and altitude limits of a minor zone or type; (10) that in some cases the local causation-factor complex may be of such a specific nature in its effect on type distinction that marked differences may be noted within the same local area, farm, or field down to within a square rod or less; (11) that in connection with the inversion of temperature between highland and lowland it is commonly found that the normal altitude position of the characterizing elements is so completely reversed as to cause widely separated and isolated islands or belts above or below this normal position; (12) that the graphic representation of minor zones by means of outline maps and charts are necessarily general, serving merely to indicate the area of prevalence and that, therefore, except for topographic sheets or maps of local areas they cannot as a rule represent the zones for specific geographic positions and places; and finally (13) that the minor zones and types as represented by specific geographic positions and places can be interpreted by characterizing elements, as by the thermal, time, and distance zonal indices, the variation index for general and local modifications, and by the local character of the zone as interpreted by the characterizing elements of the climate, biologic, ecologic, economic, and other types represented.

RELATIONS OF ZONES, CLIMATIC, PRECIPITATION, AND VEGETATION TYPES TO MAJOR AND MINOR PHYSIOGRAPHIC TYPES

The method of analyzing and tabulating the physiographic, climatic, vegetation, precipitation, and zonal elements of representative 1° quadrants across a continent, for a comparative study of their relations to the thermal zones and types, is shown in examples 57, 58, and 59 for quadrants between isophanes 43 and 44 across North America from meridian 75 to 124, inclusive.

The given physiographic types are based on the United States Geological Survey Map of the Physical Divisions of the United States by Fenneman and Johnson, and on the author's classification of types of bioclimatic zones (pp. 100–103). The vegetation types are based on the map of Natural Vegetation of the United States by Shantz and Zon, United States Department of Agriculture, 1923. The *a* zone is determined by the *average a* mean for the average altitude of the meteorological stations within each quadrant; the climatic type is determined by the relations of the plus and minus variations of the average *w* and *c* means to that of the *a* means as previously explained; and the precipitation type is the average for the year of the quadrant stations.

Example 57.—*Major and minor physiographic types across the United States between isophanes 43 and 44*

Long.	Major divisions; primary types	Provinces; major types	Sections; minor types
124–123	A. Pacific Mountain system	24. Pacific border	b. Olympic Mountains.
122	do	do	a. Puget trough.
121–120	do	23. Sierra-Cascade Mountains	a. Northern Cascade Mountains.
119–117	B. Intermontane plateaus	20. Columbia plateaus	a. Walla Walla Plateau.
116	B. Intermontane plateaus and C. Rocky Mountain system	20. Columbia plateaus and 19. Northern Rocky Mountains	
115–111	C. Rocky Mountain system	19. Northern Rocky Mountains	
110	do	19. Northern Rocky Mountains and 18. Middle Rocky Mountains	
109–107	C. Rocky Mountain system and D. Interior plains	18. Middle Rocky Mountains and 13. Great Plaius	b. Missouri plateau, unglaciated.
106–105	D. Interior plains	do	Do.
104–103	do	do	Do. c. Black Hills.
102–99	do	do	b. Missouri Plateau, unglaciated.
98	do	do	a. Missouri Plateau, glaciated, b. Missouri Plateau, unglaciated.
97	do	12. Central lowland	b. Western lake section and e. Dissected till plains.
96	do	do	Do.
95	do	do	b. Western lake section and e. Dissected till plains.
94–93	do	do	b. Western lake section.
92–91	do	do	e. Dissected till plains.
90	do	do	d. Till plains and e. Dissected till plains.
89–88	do	do	d. Till plains.
87–85	do	do	a. Eastern lake section and d. Till plains.
84–83	do	do	Do.
82	do and E. Appalachian highlands	do and 8. Appalachian Plateau	Do. and e. Kanawha section.
81–80	do	do	Do.
79	do	do	d. Allegheny Mountains.
78	do	6. Valley and ridge	b. Middle section.
77	do	4. Piedmont and 5. Blue Ridge	a. Upland, b. Lowland. a. Northern section.
76–75	F. Atlantic plain	3. Coastal Plain	a. Embayed section.

EXAMPLE 58.—*Major vegetation types across the United States between isophanes 43 and 44*

Long.	Major types	Long.	Major types	Long.	Major types
124	DF. Pacific Douglas fir.	114–112	LP. Lodgepole pine and	99	SG. Short grass and
123	DF. Pacific Douglas fir and		S. Spruce-fir and		TG. Tall grass.
	S. Spruce-fir.		BG. Bunch grass (Pacific).	98–86	TG. Tall grass and
122	DF. Pacific Douglas fir.	111–109	SG. Short grass and		OH. Oak-hickory.
121	DF. Pacific Douglas fir and		LP. Lodgepole pine and	86–83	OH. Oak-hickory.
	S. Spruce-fir.		S. Spruce-fir.	82	OH. Oak-hickory, and
120	P. Yellow pine-Douglas fir and	108	SG. Short grass and		OC. Chestnut, chestnut oak, yellow pcplar
	SB. Sagebrush.		SB. Sagebrush.	81–80	OC. Chestnut, chestnut oak, yellow poplar.
119–118	SB. Sagebrush and	107	SG. Short grass and	79	OC. Chestnut, chestnut oak, yellow poplar, and
	BG. Bunch grass (Pacific).		LP. Lodgepole pine and		
117	BG. Bunch grass (Pacific).		S. Spruce-fir		BM. Birch, beech, maple, hemlock and
116	P. Yellow pine-Douglas fir, and	106–105	SG. Short grass.		S. Spruce-fir.
	WP. Western larch-western white pine.	104–103	SG. Short grass and	78	OC. Chestnut, chestnut oak, yellow poplar.
115	WP. Western larch-western white pine and		P. Yellow pine-Douglas fir.	77–76	OC. Chestnut, chestnut oak, yellow poplar, and
	LP. Lodgepole pine.	102–100	SG. Short grass.		
					OP. Oak-pine.
				75	OP. Oak pine and
					MG. Marsh grass.

Examples 57 and 58 are self-explanatory in that where more than one longitude is given on a line it includes the area from one quadrant to the other, inclusive; in other words, the given longitude is for the east border of the quadrant. Since all the type symbol letters and numbers are defined, the only thing to keep in mind is that the given primary type, e. g., A, includes types to the next primary type, as major types 24 and 23; and that the minor type letters are for each, as 24*b*, 24*a*, 23*a*, etc.

EXAMPLE 59.—*Analysis of climatic, physiographic, vegetation, and precipitation types of quadrants*

State	Long. quad.	Aver. alt.	*a* zone	Climatic type	Physiographic: Physical map: Major	Physical map: Minor	Physical map: Section	Author's classification: Minor	Author's classification: Division	Author's classification: Section	Vegetation types	Annual preci.
	124	300	II −3	+*c*−*aw*	A	24	*b*	1	a1		DF	103.21
	123	100	−.3	+*c*−*aw*	A	24	*b*	1	a1		DF-S	22.72
	122	100	+4	+*c*−*aw*	A	24	*a*	1	a1		DF	37.27
	121	1,500	.3	+*c*−*aw*	A	23	*a*	5	a1		DF-S	80.38
Washington	120	1,800	−3+4	−*acw*	A	23	*a*	5	a1		P-SB	13.98
	119	1,300	.4	+*wa*−*c*	B	20	*a*	2	a2	*b*	SB-BG	8.47
	118	1,400	+.4	*a*−*wc*	B	20	*a*	2	a2	*b*	SB-BG	9.91
	117	2,300	−3	+*ca*−*w*	B	20	*a*	5	a1		BG	20.26
	116	1,500	+.4	+*ca*−*w*	B	20		5	a1		P-WP	21.15
					C	19						
Idaho	115	1,300	+4	−*caw*	C	19		5	a1		WP-LP	27.34
	114	3,700	.3	+*caw*	C	19		5	a1		LP-S-BG	13.03
	113	5,700	.2	+*caw*	C	19		5	a1		LP-S-BG	13.80
Montana	112	5,100	+.3	+*caw*	C	19		5	a1		LP-S-BG	12.30
	111	4,400	.3	+*caw*	C	19		5	a1		SG-S-LP	13.56
	110	5,000	+.3	+*caw*	C	19–18		5	a1		SG-S-LP	17.25
	109	4,600	−.3	+*caw*	C	18		5	a1		SG-S-LP	15.40
					D	13	*b*					
	108	4,000	.3	+*wac*	C	18		5	a1		SG-SB	6.53
					D	13	*b*					
Wyoming	107	5,600	+.3	+*caw*	C	18		5	a1		SG-S-LP	19.09
					D	13	*b*					
	106	3,900	.3	+*wac*	D	13	*b*	2	a2	*c* high	SG	13.01
	105	4,500	−3	+*wac*	D	13	*b*	2	a2	*c* high	SG	15.50
	104	4,700	+3	+*wac*	D	13	*b*–*c*	5	a2		SG-P	16.91
	103	3,400	−.3	+*wac*	D	13	*b*–*c*	5	a2		SG-P	18.82
South Dakota	102				D	13	*b*	2	a2	*c* high	SG	
	101	2,400	−.3	+*wa*−*c*	D	13	*b*	2	a2	*c* high	SG	16.21
	100	2,500	−3+4	+*wa*−*c*	D	13	*b*	2	a2	*c* high	SG	18.66
	99	1,700	+.3	+*w*−*ac*	D	13	*b*	2	a2	*c* high	SG-TG	17.14
Nebraska	98	1,600	.3	+*w*−*ac*	D	13	*a*–*b*	2	a2	*c* high	TG-OH	23.58
	97	1,300	.3	+*w*−*ac*	D	12	*b*–*e*	2	a2	*c* high	TG-OH	26.73
	96	1,200	.3	+*w*−*ac*	D	12	*e*	2	a2	*c* high	TG-OH	26.86
	95	1,400	.3	+*w*−*ac*	D	12	*b*–*e*	2	a2	*c* high	TG-OH	30.43
	94	1,200	.3	+*w*−*ac*	D	12	*b*	2	a2	*c* high	TG-OH	31.62
Iowa	93	1,000	.3	+*w*−*ac*	D	12	*b*	2	a2	*c* high	TG-OH	31.85
	92	900	−.3	+*w*−*ac*	D	12	*e*	2	a2	*c* low	TG-OH	32.89
	91	700	+4	+*w*−*ac*	D	12	*e*	6	a1	*e*	TG-OH	34.26
	90	700	+4	+*w*−*ac*	D	12	*d*–*e*	6	a1	*e*	TG-OH	33.00
Illinois	89	700	+4	+*w*−*ac*	D	12	*d*	6	a1	*c*	TG-OH	33.31
	88	600	+.4	+*w*−*ac*	D	12	*d*	6	a1	*c*	TG-OH	31.91
	87	700	+.4	+*w*−*ac*	D	12	*a*–*d*	6	a1	*c*	TG-OH	37.86
Indiana	86	700	+.4	+*w*−*ac*	D	12	*a*–*d*	6	a1	*c*	TG-OH	38.06
	85	900	.4	+*w*−*ac*	D	12	*a*–*d*	6	a2	*c*	OH	37.49
	84	1,000	+.4	+*w*−*ac*	D	12	*d*	6	a2	*c*	OH	37.14
	83	1,000	.4	+*w*−*ac*	D	12	*d*	6	a2	*c*	OH	37.89
Ohio	82	1,000	.4	+*w*−*ac*	D	12	*d*	6	a2	*b*	OH-OC	38.88
					E	8	*e*					
	81	700	.4	+*aw c*	E	8	*e*	6	a2	*b*	OC	41.23
West Virginia	80	900	.4	+*ac*−*w*	E	8	*e*	6	a2	*b*	OC	43.56
	79	1,900	.4	+*caw*	E	8	*d*	5	a3		OC-BM-S	45.36
	78	900	.4	+*awc*	E	6	*f*	5	a3		OC	36.84
Virginia	77	400	−.4	+*wa c*	E	4–5	*a*–*b*, *a*	3	a1	*b*	OC-OP	39.56
Maryland	76	100	−4+5	+*wac*	F	3	*a*	3	a1	*a*	OC-OP	42.27
	75	0	+5	+*cwa*	F	3	*a*	3	a1	*a*	OP-MG	43.00

Example 59 gives the States; longitude quadrants; average altitude of the record positions for each quadrant; its *a* zone and climatic type; its physiographic major, minor, and section types from example 57 or the physical map; the minor, division, and section types of the author's classification; and the vegetation and annual precipitation types. Under climatic types, +*caw* or +*wac* signifies that all variations are warmer, and −*caw* or −*wac* that all are colder than the isophane requirement constants as charted. When, however, one or two letters are plus and the other one or two are minus it signifies that the plus variation is above the base isophane and warmer, and the minus variation is below it and colder, than the constant, thus representing minor types of the major type. When there is no variation (or normal), the type symbol is given as *awc*, and when the relations represent a transition between the two major types they are represented by various combinations such as −*acw* for quadrant 120, *a*−*wc* for 118, +*awc* for 81, +*ac*−*w* for 80, and +*awc* for 78.

It will be noted that by this principle and symbolic method the more important physiographic and bioclimatic elements of geographic quadrants may be readily determined and tabulated for comparative study. For additional minor bioclimatic elements the analysis of quadrant types could be extended to any desired limit of the position records as for Lafayette, Ind., in examples 53 and 54.

It is to be kept in mind that in addition to the general types, as determined from averages of record positions and from physical, vegetation, soil, and other maps, there may be many local zones, zonal, climatic, and other types as controlled by the range in altitude and other topographic features, with corresponding minor vegetation, ecological, economic, and agricultural types. Hence, to give a more complete picture of the relations of major and minor types, a complete bioclimatic analysis of a given quadrant, local region, or geographic position would require the inclusion of all recorded and observed elements.

It is a significant fact, however, that the thermal *a* zone and *w* and *c* zonal types, together with the major and minor climatic (thermal) types and precipitation types, will serve as indices to a wide range of preliminary information of great value to scientific research and economic practice in agriculture.

POLEWARD AND EQUATORWARD TREND OF MAJOR TYPES

By reference to the physiographic, vegetation, climatic, weather, precipitation, and soil maps, it will be seen that there is often a poleward and equatorward (longitudinal) trend of these types which in their range may cross one or more major zones and many minor zones. For example, the major *caw* or *wac* climatic types may extend across all of the major zones and all of their minor zones. Thus, a coast or a connected series of mountain ranges with their major *caw* type, such as the west and east coasts of North America, may extend through all of the zones from north poleward to south poleward, with in some cases all of the zones represented vertically from tropical major III to the arctic alpine of major I.

Therefore a given minor zone, as minor 4 of major II, in its broken range and distribution from the east to the west coasts of North America has its bioclimatic features modified by a large number of major and minor physiographic, climatic, and weather types, and consequently has a large number of vegetation types, from humid rain forests to deserts, and with economic types from highly productive types to those in which there is little or no profitable production.

VALUE OF THIS PRINCIPLE AND METHOD

The significance of this combination and analysis of major and minor types is in the fact that, if a given characteristic combination of types prevails within a given local region and the same or similar combination is found to prevail in any other region of the same or any other continent, it may be safely assumed that the same type of plants and animals, if not the same species, will be found and that the same type of agriculture will be suitable, having insects and diseases with the same type of seasonal history. Moreover, any species or variety introduced from one of these regions to the other—no matter how far they may be separated—will be more likely to succeed than if it is introduced into a region of the same zone but with a different combination of zonal types.

It is obvious that a species transferred from a rain-forest type to a semidesert type of the same minor zone, or vice versa, would not succeed, but if a rain-forest species is introduced to another rain forest of the same zone on that or a different continent it would succeed, or at least the chances in its favor would be great. Thus it will be seen that the recognition and interpretation of the bioclimatic zone and its thermal and bioclimatic types for any given region or place is the basis of preliminary information for constructive scientific research and economic practice in agriculture.

The most important fact of all, however, is that *by the bioclimatic principle and method preliminary information on the combination of zonal types, interpreted from published thermal and other records at representative positions with very little cost, in many cases will be just as reliable as if the same preliminary information were secured by field explorations, the cost of which in some cases would be prohibitive.*

Thus the *a* zone represented by a local area or place will indicate the range of the average temperature; the *w* zonal type will indicate the character of the summer temperature; the *c* zonal type, that of the winter temperature; and the relations of the *a*, *w*, and *c* variations to each other will indicate the major climatic type, which may be continued to any number of minor types for which records and facts are available.

TIME ELEMENTS OF ZONAL TYPES

The time elements of zonal types consist of dates and periods in days of the seasons, relative length of daytime and nighttime, and other elements expressible in units of time, as related to geographic positions, quadrants, and local regions. Season types are controlled by the motions of the earth, modified by the major and minor physiographic features of its surface.

Thus while temperature is a fundamental index to the thermal element of climate, especially of the major and minor thermal elements of the bioclimatic zone and zonal types, time by dates and periods in days is a fundamental measure of seasonal progress in the march of temperature with latitude and altitude and is an index to the type of the seasons at any given place, as characterized by the date of beginning, progress, ending, length in days, dates of latest killing frost in spring and earliest in autumn, and length of the frostless season,

all of which have been discussed in more or less detail in preceding sections.

PHENOLOGICAL TYPES

The phenological types of a given thermal or bioclimatic zone are characterized by dates and periods of the seasonal phenomena of plants or animals, or of farm and garden practice, and thus involve one of the very important time elements in bioclimatics.

The phenological type is closely related to the thermal, climatic, and other seasonal types of a minor zone, but is of even greater importance in serving as a measure of the relative effects of the local causation-factor complex on plants and animals. It is in some respects more important than temperature in identifying the local type of a season zone, since *subjects are available for observation and record wherever plants grow*, while temperature records are, as a rule, available only from more or less widely separated record positions.

As compared with records of thermal and other elements of climate, however, there are exceedingly few positions in the world where consecutive phenological and other time records have been kept for a sufficient period to be of special value in the interpretation of phenological types. Nevertheless, this lack of phenological records as indices to the season types to a certain extent is compensated for by the monthly mean index to the dates of the beginning of the seasons and their length in days, which thus serves to give important preliminary information that otherwise would be secured from phenological records.

The methods of interpreting the time types of a given minor zone are similar to those followed in the interpretation of thermal and bioclimatic types in that, so far as available and practicable, position records are referred to table 9 or to other tables of time constants with their scale of zonal constants, as has been fully discussed and illustrated in preceding sections.

INTERPRETATION OF RANGES AND LIMITS OF ZONES AND TYPES

METHODS OF PROCEDURE

There are several methods of procedure in the interpretation of the ranges and limits of zones, sections, and types by appendix table 10; (1) by the *avx* altitude variation index and the *ax* altitude index; (2) by the *lvx* latitude variation index and the *ix* isophane index; (3) by the timber line *avx;* (4) by topographic contour maps; (5) by the adjustable isophane-altitude scale; and (6) by the topographic profile, in all of which the *lvx* and *avx* are the basic indices to the interpretation of the zones, zonal colimits, and zonal types represented by record or nonrecord altitude positions on or near a given *pi* within a local area, coming within the same modifying influences as that represented by a determined *lvx* or *avx* for a representative record position or by the average *lvx* or *avx* of two or more record positions.

INTERPRETATION BY THE ALTITUDE INDEX

The procedure in the application of the *avx* to the altitude and zonal constants for a given *pi* in table 10, in order to find the *ax* to the modified altitudes for the same zones or zonal colimits, is simply to add the determined plus *avx* to, or subtract the minus *avx* from, the colimit altitude constants of a given *pi*, which gives the corresponding modified or *ax* altitude positions for the same colimits. Then any intervening altitude between those of the colimits will represent the intervening minor zone or type for the same altitude on the *pi*, as in example 60 for the Buffalo *pi* 43, in which *ac* gives the series of colimit altitude constants for the *pi* in table 10; *zc* the *ma* major and *mi* minor zonal colimits for *ac*; then *a avx* gives the position *avx* by the record *a* annual mean for Buffalo, Wyo., which plus the *ac* altitudes gives the modified *ax* for the same colimits but 2,300 feet above their *ac*. Thus any altitude coming between those of the colimit altitude constants on the position isophane will represent the intervening zonal *constant*, as 4,600 feet between zonal colimits −1+2 and −2+3 represents zonal constant minor 2; while in the modified series it comes between colimits −2+3 and −3+4 and consequently represents interpreted *a* zone 3. In the same way the modified *w* and *c* types are determined for any altitude on the *pi* by referring it to the same altitude in the modified series. Example 61 illustrates the same *avx* and *ax* method as in example 60 in which the *avx* is minus, thus giving a lower modified *ax* for the colimits.

EXAMPLE 60.—*Interpretation of zonal colimits by the altitude index for isophane 43 of the Buffalo, Wyo., quadrant*

zc ma	I II	II	II	II	II	II	II	II III	III
mi	−4+1	−1+2	−2+3	−3+4	−4+5	−5+6	−6+7	−7+1	−1+2
ac	6,800	5,600	3,200	2,000	0	−1,200	−3,600	−5,200	−7,600
a avx	+2,300	+2,300	+2,300	+2,300	+2,300	+2,300	+2,300	+2,300	+2,300
a ax	9,100	7,900	5,500	4,300	2,300	1,100	−1,300	−2,900	−5,300

EXAMPLE 61.—*Interpretation of zonal colimits by the altitude index for isophane 43.25 of the Tatoosh Island, Wash., quadrant*

zc ma	I II	II	II	II	II	II	II	II III
mi	−4+1	−1+2	−2+3	−3+4	−4+5	−5+6	−6+7	−7+1
ac	6,700	5,500	3,100	1,900	−100	−1,300	−3,700	−5,300
a avx	−1,900	−1,900	−1,900	−1,900	−1,900	−1,900	−1,900	−1,900
a ax	4,800	3,600	1,200	0	−2,000	−3,200	−5,600	−7,200

INTERPRETATION BY THE ISOPHANE INDEX

The procedure in the application of the *lvx* latitude variation index to the *ix* and modified altitudes for the zonal colimits in table 10 is simply to substract the minus *lvx* from, or add the plus *lvx* to, a given *pi*, which gives in table 10 the corresponding *ix* to the modified altitudes for the same colimits as those for the *pi* and *ac*, so that (as by the *avx* and *ax* method) any altitude on the *pi* referred to the altitude series for the modified or *ix* will indicate the zone or type it represents. In the same way the *lvx* for a given representative record position will apply to the other isophanes of a local area or geographic quadrant coming within the same modifying influences as that represented by the *lvx* and *avx* of the record position.

EXAMPLE 62.—*Isophane and altitude indices for the Buffalo quadrant as indices to the zones of nonrecord positions*

ix	−1+2	2				−2+3	3		−3+4
37.75	7,700	7,400	6,800	5,800	5,500	5,300	4,800	4,400	4,100
37.50	7,800	7,500	6,900	5,900	5,600	5,400	4,900	4,500	4,200
37.25	7,900	7,600	7,000	6,000	5,700	5,500	5,000	4,600	4,300
37.00	8,000	7,700	7,100	6,100	5,800	5,600	5,100	4,700	4,400
36.75	8,100	7,800	7,200	6,200	5,900	5,700	5,200	4,800	4,500

Example 62 illustrates the method of applying the minus *lvx* for the Buffalo, Wyo., quadrant to the 0.25° isophane-longitude quadrant assumed to come under the same modifying influence, in which the position

and unmodified isophanes are 43.50, 43.25, 43.00, 42.75, and 42.50 which minus the *a lvx* 5.75 gives the corresponding modified isophane indices 37.75, 37.50, 37.25 37.00, and 36.75; and these referred to table 10 give the modified altitudes for the *a* colimits and zones of the unmodified position isophanes as shown. Thus the altitude of any record or nonrecord position within the range of the Buffalo quadrant referred to its corresponding *ix* in example 62 will give the *a* zone represented by it; and in the same way the *w* and *c* zonal types are found. Application of the plus *lvx*, as for Tatoosh Island, is by the same method of procedure.

It will be apparent that the *ix* method as applied to table 10 for the interpretation of zones and types for specific record and nonrecord altitude positions has advantages over the *ax* method in that it is available for immediate application to table 10 to find the zone or types for all altitudes. Although the *ax* method has its advantages in finding the zone or types represented by any specific record or nonrecord position on a given *pi* or in a given quadrant, the *lvx* is best to include all altitudes within the quadrant.

While the *lvx* for a given record position may apply to any altitude position within a 0.25°, 0.50°, or 1° quadrant, it depends on whether or not the prevailing modifying influences are the same or near that prevailing at the representative record position or positions (example 66).

It is important to keep in mind that there is a distinction between the *ri* and the *ix* as applied to table 10, in that the *ri* applies only to the isophane zonal scale to find the zone or type represented by a record altitude position, while the *ix* is the modified *pi* applied to the isophane scale only, because its zones are represented by the modified altitude series.

THE ISOPHANE-ALTITUDE CHART OF DISTANCE CONSTANTS

To provide for the extension of the isophane-altitude and zonal colimit constants of appendix table 10 and to illustrate another method (1) of finding the zonal constants for altitudes above a given sea-level isophane and (2) of interpreting the modified altitudes of the zones by the *ax* and *ix* principles, an isophane-altitude chart was developed as shown in figure 55.

One feature in the method of applying the *lvx* and *avx* indices and *ax* to the chart is the reverse of their application to table 10, in that the *pa* of the chart minus the determined plus or plus the determined minus *avx* gives the modified altitude and its interpreted zone on the *pi*. The application of the *lvx* is, however, the same in both the table and chart in that the minus *lvx* is subtracted from, and the plus *lvx* is added to, the *pi* to find the *ix* on which the *pa* gives its modified zones.

One of the advantages of the chart is that it eliminates the use of altitudes below sea level for the application of the plus *avx* as in table 10, because the isophanes below a given *pi* represent the zones below sea level, e. g., for *pi* 43 with its sea-level zonal colimit −4+5, the zonal series below sea level is the same as for isophanes 42 to 0.

INTERPRETATION BY THE TIMBER-LINE INDEX

The subject of climatic timber line and the interpretation of its altitude limits from poleward sea-level to equatorward altitude limits has been fully outlined on pages 49–55 of part 1 with test examples and charts.

METHODS OF PROCEDURE

The methods of procedure for the interpretation of the altitude of the timber-line zone and the altitudes of corresponding zonal colimits and zones are the same as previously described for interpretations by table 10, in that the representative *lvx* and/or *avx* are determined for a given record timber-line position, and these are utilized to modify the altitude constants for timber line as given in table 10 under zonal colimit II −1+2, and shown in example 63.

EXAMPLE 63.—*Alpine timber-line data for representative mountains*

Continent: North America; No. 29; Position: Mount Rainier, Wash.; *pl*, 46.75° N.; *plo*, 121 W.; *pi*, 42.50 N.; *tl-pr*, 6,000; *ac*, 5,800; *avx*, +200

		I+4	*sl*	II+1	−1+2	+3	+4	+5	*zl*
pi	42.50	9,600	8,200	7,000	5,800	3,400	2,200	200	*ac*
lvx	−.50	+200	+200	+200	+200	+200	+200	+200	*avx*
ix	42.00	9,800	8,400	7,200	6,000	3,600	2,400	400	*ax*

Continent: North America; No. 2; Position: Mount Washington, N. H.; *pl*, 44.25° N.; *plo* 71 W.; *pi*, 50.00 N.; *tl-pr*, 4,000; *ac*, 2,800; *avx*, +1,200

		I+4	*sl*	II+1	−1+2	+3	+4	*zl*
pi	50.00	6,600	5,200	4,000	2,800	400	−800	*ac*
lvx	−3.00	+1,200	+1,200	+1,200	+1,200	+1,200	+1,200	*avx*
ix	47.00	7,800	6,400	5,200	4,000	1,600	400	*ax*

Continent: South America; No. 4; Position: Mount Chimborazo, Ecuador; *pl*, 1.25° S.; *plo*, 78 W.; *pi*, 2.25 N.; *tl-pr*, 15,600; *ac*, 21,900; *avx*, −6,300

		I+2	+3	+4	*sl*	II+1	−1+2	+3	+4	+5	+6	+7	III+1	+2	*zl*
pi	2.25	33,100	29,100	25,700	24,300	23,100	21,900	19,500	18,300	16,300	15,100	12,700	11,100	8,700	*ac*
lvx	+15.75	−6,300	−6,300	−6,300	−6,300	−6,300	−6,300	−6,300	−6,300	−6,300	−6,300	−6,300	−6,300	−6,300	*avx*
ix	18.00	26,800	22,800	19,400	18,000	16,800	15,600	13,200	12,000	10,000	8,800	6,400	4,800	2,400	*ax*

Continent: Europe; No. 25; Position: Pyrenees, France; *pl*, 42.50° N.; *plo*, 0; *pi*, 22.50 N.; *tl-pr*, 7,400; *ac*, 13,800; *avx*, −6,400

		I+2	+3	+4	*sl*	II+1	−1+2	+3	+4	+5	+6	+7	*zl*
pi	22.50	25,000	21,000	17,600	16,200	15,000	13,800	11,400	10,200	8,200	7,000	4,600	*ac*
lvx	+16.00	−6,400	−6,400	−6,400	−6,400	−6,400	−6,400	−6,400	−6,400	−6,400	−6,400	−6,400	*avx*
ix	38.50	18,600	14,600	11,200	9,800	8,600	7,400	5,000	3,800	1,800	600	−1,800	*ax*

Example 63.—*Alpine timber-line data for representative mountains*—Continued

Continent: Asia; No. 1; Position: Fuji Yama, Japan; *pl*, 35.25° N.; *plo*, 138 E.; *pi* 42.75 N.; *tl-pr*, 6,000; *ac*, 5,700; *avx*, +300

	1+2	+3	+4	*sl*	II+1	−1+2	+3	+4	+5	*zl*
pi 42.75	16, 900	12, 900	9, 500	8, 100	6, 900	5, 700	3, 300	2, 100	100	*ac*
lvx −.75	+300	+300	+300	+300	+300	+300	+300	+300	+300	*avx*
ix 42.00	17, 200	13, 200	9, 800	8, 400	7, 200	6, 000	3, 600	2, 400	400	*ax*

Continent: Africa; No. 3; Position: Mount Kenya, Kenya; *pl*, 1.00° S.; *plo*, 37 E.; *pi*, 13.50 S.; *tl-pr*, 13,000; *ac*, 17,400; *avx*, −4,400

	1+2	+3	+4	*sl*	II+1	−1+2	+3	+4	+5	+6	+7	III+1	*zl*
pi 13.50	28, 600	24, 600	21, 200	19, 800	18, 600	17, 400	15, 000	13, 800	11, 800	10, 600	8, 200	6, 600	*ac*
lvx +11.00	−4, 400	−4, 400	−4, 400	−4, 400	−4, 400	−4, 400	−4, 400	−4, 400	−4, 400	−4, 400	−4, 400	−4, 400	*avx*
ix 24.50	24, 200	20, 200	16, 800	15, 400	14, 200	13, 000	10, 600	9, 400	7, 400	6, 200	3, 800	2, 200	*ax*

Continent: Australia; No. 2; Position: Australian Alps; *pl*. 37.00° S.; *plo*, 148 E.; *pi*, 27.50 S.; *tl-pr*, 5,500; *ac*, 11,800; *avx*, −6,300

	I+2	+3	+4	*sl*	II+1	−1+2	+3	+4	+5	*zl*
pi 27.50	23, 000	19, 000	15, 600	14, 200	13, 000	11, 800	9, 400	8, 200	6, 200	*ac*
lvx +15.75	−6, 300	−6, 300	−6, 300	−6, 300	−6, 300	−6, 300	−6, 300	−6, 300	−6, 300	*avx*
ix 43.25	16, 700	12, 700	9, 300	7, 900	6, 700	5, 500	3, 100	1, 900	−100	*ax*

This example illustrates the methods of finding the *avx* and *lvx* and their application to the timber-line constants for the timber-line zone −1+2 in table 10 to find the corresponding modified altitudes for the colimits and zones above and below timber line on the record *pi*, in which *pi* plus or minus the *lvx* variations gives *ix* and the series of modified altitudes and *zl* zonal limits including the modified altitudes for −1+2, timber line, and *sl* snow line, as shown. In a like manner the difference between the *tl-pr* timber-line position record and the *ac* altitude constant for the *pi* gives the plus or minus *avx*, which plus or minus the *ac* for *pi* in table 10 gives the *ax* or modified altitudes for timber-line, snow-line, and corresponding zonal colimits and zones, which are the same as by the *ix* method.

The given seven representative mountains are from a list of available timber-line records and interpretations for sea-level and alpine positions representing all continents. North America 29, Mount Rainier, Wash., of the list represents a western coast region and 2, Mount Washington, N. H., an eastern region of the continent; South America 4, Mount Chimborazo, Ecuador, represents the northern Andes and the equatorial region of South America; Europe 25, Pyrenees, France, represents an average for southwestern Europe and the Mediterranean region; Asia 1, Fuji Yama, Japan, represents eastern Eurasia and the insular region of Japan; Africa 3, Mount Kenya, Kenya, represents eastern Africa and its equatorial region; and Australia 2, Australian Alps, represents eastern Australia. Following the number and name the coordinates of each geographic position are given under *pl* position latitude, *plo* position longitude, *pi* position isophane, and *tl-pr* timber-line position as recorded in literature or as interpreted from different altitudes given by different authors.

South America 4 is a good example of the application of the timber-line index because on its isophane 2.25 N. the elevation rises from sea level on the Pacific coast to, and above, snow line. Here the *pi* 2.25 N. gives in table 10 the constant for timber line −1+2 at 21,900 feet, which minus the record at 15,600 feet gives an *avx* of −6,300 feet, which minus the *ac* gives *ax* 15,600 feet for the altitude of timber line under −1+2, and the corresponding interpreted upper limits of the major and minor zones from major III minor +2 at 2,400 feet to major I minor +2 at 26,800 feet; or *lvx* +15.75 plus *pi* 2.25 gives *ix* 18, which referred to table 10 gives the same interpreted limits as by the *avx*.

This method applies in the same way to any other position, and, while the variations determined by the timber-line record may not apply as well to the lower elevations without further modification for topographic and other physiographic influences, they will serve as broad general preliminary interpretations of the ranges and limits of the minor zones for the local region represented by the variation for the record timber-line position.

It is of special interest to note the difference in the variations of the recorded from the constant altitude for different timber-line positions on the continents as:

	avx Feet
29. North America—Mount Rainier	+200
2. North America—Mount Washington	+1, 200
4. South America—Mount Chimborazo	−6, 300
25. Europe—Pyrenees	−6, 400
1. Asia—Fuji Yama	+300
3. Africa—Mount Kenya	−4, 400
2. Australia—Australian Alps	−6, 300

Thus for North America 29 and 2 and Asia 1 the variations are plus and warmer with the record altitudes higher than their constants, while for the other positions they are minus, which signifies much colder influence, with the records very much lower than their requirement constants.

That these variations are as nearly correct as could be expected is quite plainly indicated by variations based on thermal records and the constants of appendix table 3 for the same quadrants, or within the same local regions of the given mountains. It thus appears that the timber-line index to the altitude ranges and limits of the zones of a mountain and its region is as reliable as the indices based on thermal records.

Example 64.—*Comparison of variations and interpreted zonal limits in the Himalaya, Tian Shan, and Mount Slamet*

No. 6; Position, Himalaya, Tibet; *pl*, 35.00° N.; *plo*, 80; *pi*, 31.00 N.; *tl-pr*, 14,500; *ic*, 10,400; *avx*, +4,100; *lc*, 8,800; *avx*, +5,700

	zl	I+2	+3	+4	II+1	−1+2	+3	+4	+5
ix 20.75	*ax*	25, 700	21, 700	18, 300	15, 700	14, 500	12, 100	10, 900	8, 900

EXAMPLE 64.—*Comparison of variations and interpreted zonal limits in the Himalaya, Tian Shan, and Mount Slamet*—Con.

No. 8; Position, Tian Shan, China; *pl*, 41.00° N.; *plo*, 76; *pi*, 36.25 N.; *tl-pr*, 9,000; *ic*, 8,300; *avx*, +700; *lc*, 6,400; *avx*, +2,600

	zl	I+2	+3	+4	II+1	−1+2	+3	+4	+5
ix.........34.50	*ax*	20,200	16,200	12,800	10,200	9,000	6,600	5,400	3,400

No. 1; Position, Mount Slamet, Java; *pl*, 7.00° S.; *plo*, 109; *pi*, 5.50 S.; *tl-pr*, 9,200; *ic*, 20,600; *avx*, −11,400; *lc*, 20,000; *avx*, −10,800

	zl	I+4	II+1	−1+2	+3	+4	+5	+6	+7
ix.........34.00	*ax*	13,000	10,400	9,200	6,800	5,600	3,600	2,400	0

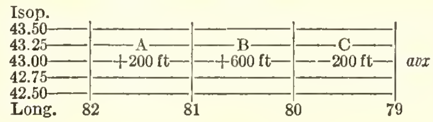
It is of special interest to note that the altitude limits of a given zone in the equatorial region, or in southern latitudes, may be at the same level or even lower than that for the same zone many degrees north in the Northern Hemisphere, as for example that of Java, latitude 7° S., and of western China, latitude 41° N., as shown in example 64, which gives three additional positions from the general list to illustrate extreme isophane and latitude *avx*, and shows that the altitude position of timber line near the Equator may be even lower or but little higher than that of a position much farther north. The principle, symbols, and method in this example are the same as in example 63, except that the *ac* for the *pl* and the latitude *avx* are given for comparison with the *ic* and *avx*.

the North Pole. The most surprising feature is this evidence (examples 63 to 65) that the summits of the highest mountains of the continents extend far above an equivalent in latitude, and consequently temperature, to that of the North or South Poles.

INTERPRETATION BY THE TOPOGRAPHIC-MAP METHOD

Since the contours of a topographic map give the altitude of any given place within its boundaries, they serve at once as altitude indices to the zonal constants, which corrected by the required *avx* give the modified altitudes for the colimits and the intervening zones.

EXAMPLE 66.—*Quadrant units for the interpretation of zonal limits by the altitude index*



Example 66 represents three 1° quadrants between longitudes 79 and 82 with four 0.25° isophanes from 42.50 to 43.50, in which quadrant A represents an *avx* of +200; B, +600; and C, −200 feet. While such a wide difference in the *avx* for adjoining quadrants would rarely occur, this is given here to serve in the further discussion of the topographic map principle under example 67 and figures 39 and 40.

EXAMPLE 65.—*Interpreted altitude zonal limits for Mount Everest*

	pl	*plo*	*pi*	Isophane			Latitude	
				tl-pr	*pc*	*avx*	*pc*	*avx*
Mount Everest..............................	28.00° N....	87	30.50 N.....	13,500	10,600	+2,900	11,600	+1,900

	Summit	*zl*	I+1	+2	+3	+4	II+1	−1+2	+3	+4	+5	+6	+7	III+1	+2
ix 23.25..............................	29,000	*ax*	26,700	24,700	20,700	17,300	14,700	13,500	11,100	9,900	7,900	6,700	4,300	2,700	300

It will be noted that the record average altitude of timber line in the Himalayas in latitude 35° N. is much higher than that for Mount Slamet in latitude 7° S.; and that on Tian Shan, latitude 41° N., it is only 200 feet lower than on Mount Slamet, 48° farther south.

ZONAL LIMITS FOR MOUNT EVEREST

It is of interest in this connection to compare the interpreted vertical zones for Mount Everest, altitude 29,000 feet, with the altitude constants from the Equator to the poles in appendix figure 55. While no record data for timber line on this mountain are available to the writer, it is evident from the average of the records for the Himalayas that it would come between 13,000 and 14,000 feet, or at an average of 13,500 feet, with the altitude indices for the zones of the local region and mountain as in example 65, which gives the interpreted altitude limits above sea level from 300 feet for major zone III minor +2 to 26,700 feet for major I minor +1. Thus with 26,700 feet equivalent to the pole, the summit at 29,000 feet is 2,300 feet above the upper or poleward limit of major zone I, which is equivalent to (2,300÷400) 5.75° of latitude beyond

EXAMPLE 67.—*Method of correcting the altitude colimit zonal constants by the altitude variation index for position isophanes in quadrant A, example 66*

pi	*zc*	I−4II+1	II−1+2	−2+3	−3+4	−4+5
43.50..	*ac*	6,600	5,400	3,000	1,800	−200
	avx	+200				
	ax	6,800	5,600	3,200	2,000	0
43.25..	*ac*	6,700	5,500	3,100	1,900	−100
	avx	+200				
	ax	6,900	5,700	3,300	2,100	100
43.00..	*ac*	6,800	5,600	3,200	2,000	0
	avx	+200				
	ax	7,000	5,800	3,400	2,200	200
42.75..	*ac*	6,900	5,700	3,300	2,100	100
	avx	+200				
	ax	7,100	5,900	3,500	2,300	300
42.50..	*ac*	7,000	5,800	3,400	2,200	200
	avx	+200				
	ax	7,200	6,000	3,600	2,400	400

In example 67 the *pi* is referred to table 10 to find the *ac* for the *zc* zonal colimit constants, and by the *ac* plus the *avx* 200 feet to find the *ax* to the positions of the zonal colimits as in figure 39. While the data for isophanes 42.50 to 43.25 cover each of the four 0.25°, the data for 43.50° are given for the lower quarter of the next quadrant above.

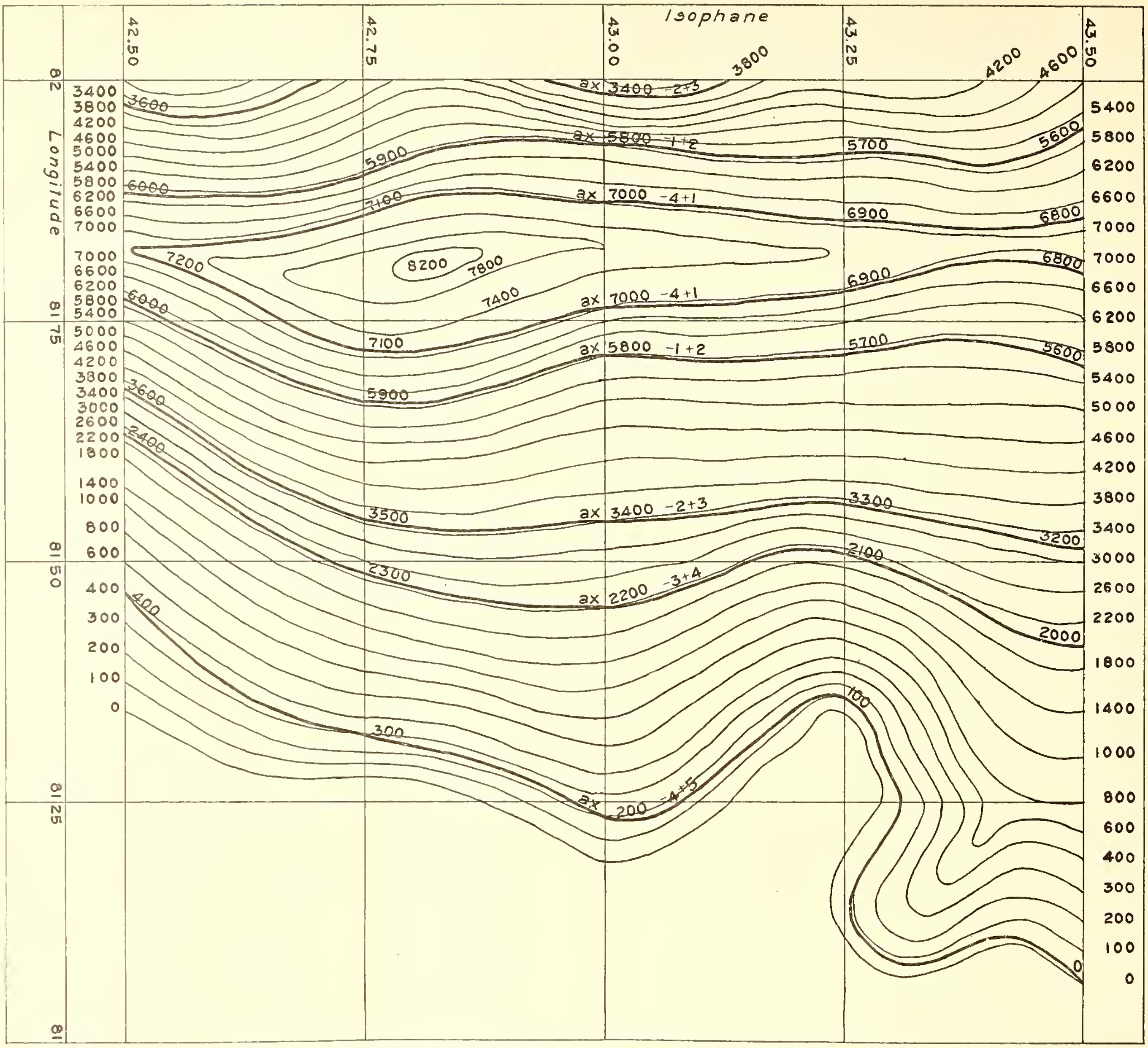


FIGURE 39.—Generalized contour map with interpreted positions for the colimits and ranges of zones.

Figure 39 represents the assumed topographic contours for quadrant A of example 66 which are drawn to represent intervals of 100 feet between sea level and 400 feet; 200 feet between 400 and 1,000 feet; and 400 feet between 1,000 feet and the highest summit at 8,200 feet, with an altitude variation index of +200 feet for the quadrant, and with the interpreted positions of the minor zonal colimits from II−4+5 to I−4II+1.

The method of procedure is to find for each isophane, as in example 67, the position of the corrected (*ac* + *avx* 200 feet) colimits with each position marked by a dot. When this process is completed for each isophane and colimit the dots are connected by a freehand line.

Thus with the altitude indices to the colimits determined for each isophane as in example 67 it is a simple matter to find and mark their relative positions on or between the contours and to draw in the colimit lines. When this is done, it will show at once not only at what altitude a given colimit may be expected to occur on and between the isophanes but also the altitude range of the intervening minor zone, e. g., zone 4 between colimits −4+5 and −3+4 anywhere between 200 feet and 2,200 feet on isophane 43; between sea level and 2,000 feet on isophane 43.50; or between 400 feet and 2,400 feet on isophane 42.50; and so on for the other minor zones, with timber line (−1+2) ranging from 5,600 feet on isophane 43.50 to 6,000 feet on isophane 42.50, and with snow line at about 8,100–8,200 feet between isophanes 43 and 42.75.

GRADATION IN VARIATION INDICES

In example 67 and figure 39 the *avx* is the same for all of the isophanes of the quadrant, but when the variation indices for two or more adjacent 1°, 0.50°, or 0.25° quadrants, or for different isophanes of the same quadrant, differ by 100 feet or more, it is necessary to adopt a method of gradation from that of one isophane or quadrant to the one on either side of it, in order that the interpreted colimit lines will connect from one quadrant to the other. The principle of this method

and its application is illustrated in figure 40 in which two 1° quadrants between isophanes 42.50 and 44.50 and between longitudes 81 and 82 are given, with sixteen 0.25° quadrants in each. The vertical lines represent contours at intervals of 100 feet from 1,200 feet to 2,800 feet. The A 1° quadrant is assumed to have a general average *avx* of +400 feet as given on isophane 44, while quadrant B is assumed to have a general average *avx* of −400 feet as given on isophane 43.

Line *ac* represents the colimit constant for minor zones −3+4 which rises southward at the rate of 100 feet to each 0.25° isophane from 1,400 feet on isophane 44.50 to 2,200 feet on isophane 42.50; *ax* represents the modified colimit line for −3+4, as determined by gradation in the *avx* from plus 400 feet on isophane 44.00 to 0 (no variation) on isophane 44.50 and 43.50,

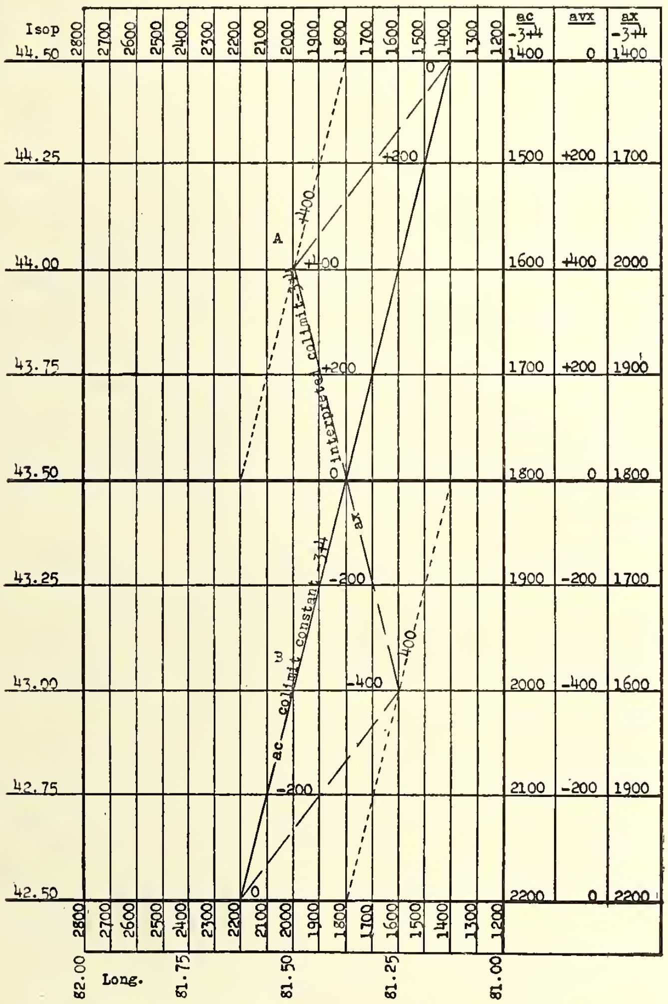


FIGURE 40.—Interpretation of zonal colimits by gradations in altitude variation indices.

and from minus 400 feet on isophane 43.00 to 0 on isophanes 43.50 and 42.50.

The given altitudes above the upper and below the lower borders are for contour intervals of 100 feet. The vertical spaces to the right give the *ac* for the colimit constants on the isophanes from 1,400 feet on the north border to 2,200 feet on the south; *avx*, the average and modified altitude variation indices for each isophane; and *ax* (*ac* ± *avx*) the altitude indices to the modified altitudes of the interpreted colimits. The light broken lines for +400 feet in quadrant A from 1,800 feet on isophane 44.50 to 2,200 feet on isophane 43.50, and in quadrant B for −400 feet from isophane 43.50 at 1,400 feet to 42.50 at 1,800 feet show where the modified colimit lines would come if the average plus and minus 400 foot variation indices were applied to all of the isophanes of each quadrant, and how widely they would be separated on isophane 43.50°.

It will be recognized that on a regular contour map the *ac* and *ax* colimit lines and the contours would appear as curves instead of straight lines, but this diagram serves to illustrate the principle.

When the quadrants to the east or west of a given quadrant have different variation indices, a similar gradation is required, so that there would be a gradual change and a smoothed zonal colimit line from one quadrant to the other.

It is this principle of modification in dealing with two or more quadrants that must be applied for the more correct interpretation of continuous colimit lines in the development of a zonal map. By this method zonal maps have been made with very satisfactory results for the United States, several States, a number of topographic sheets, and for several other countries, in verification of this principle and method.

INTERPRETATION BY THE ADJUSTABLE-SCALE METHOD

Since the *avx* is applied to the *ac* of table 10 to find the modified altitudes of the colimits or zones for a given *pi*, a simplified method to attain the same results is desirable. To meet this need the writer devised a simple adjustable scale for direct application of the determined *avx* to the *ac* for any given *pi*, as illustrated in figures 41 and 42 and example 68.

Figure 41 shows an end view of the adjustable isophane-altitude scale in which *A*, *b*, and *c* form the

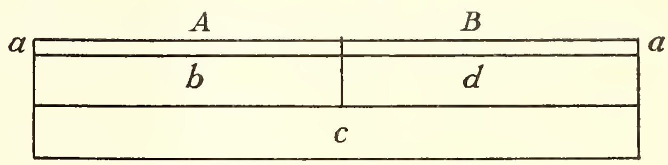


FIGURE 41.—Method of constructing the adjustable scale.

stationary part and *B* and *d* the adjustable part to slide on the base *c*. The parts are made either of thick cardboard or thin wood.

Figure 42 shows the stationary scale A with its *si* sea-level isophanes in quarter degrees; *zc* the corresponding zonal constants for *ma* II and *mi* 4; and *ms* the colimits of minor sections; while adjustable scale B gives the *ac* for isophane 43, corresponding in vertical positions to the horizontal series for the same isophanes in table 10 but for intervals of 100 feet, each of which is equivalent to a 0.25° isophane, so that 300 feet is

equivalent to isophane 43.75 and its colimit zonal sections −.4 and −4; 600 feet, to isophane 44.50 and .4 and −.4; and so on to 2,000 feet, which is equivalent to isophane 48.00 and its zonal colimit −3+4.

Stationary Scale A				Adjustable Scale B
ZC				
ma	mi	ms	si	ac
II	3	-3	48.00	2000
	4	+4	.75..	...1900
			.50..	...1800
		+4	.25	1700
		+.4	47.00..	...1600
			.75..	...1500
		+.4	.50	1400
		.4	.25..	...1300
			46.00..	...1200
			.75..	...1100
			.50..	...1000
			.25..	900
			45.00..	800
			.75..	700
		.4	.50	600
		-.4	.25..	500
			44.00..	400
		-.4	.75	300
		-4	.50..	200
			.25..	100
	4	-4	43.00	0
	5	+5		

FIGURE 42.—The zonal isophanes and altitude scales.

Thus with 0 of the *ac* scale adjusted to isophane 43, the zonal and sectional colimit constants for each altitude on isophane 43 are at once found in the zonal scale.

The scale of isophanes in quarter degrees and the scale of altitudes at intervals of 100 feet provide for a more specific interpretation of the corresponding colimits of minor zones and zonal sections, but for general interpretations of zonal colimits on a contour map the 1° isophanes and corresponding altitudes at intervals of 400 feet are sufficient. For application to all isophanes and altitudes, sections of the stationary A scale are each provided with about thirty 1° isophanes as (1) from 0 to 30°, (2) from 30 to 60°, and (3) from 60 to 90°. Then with corresponding adjustable scales as (1) from 0 to 11,300 feet, (2) from 11,300 to 22,600 feet above sea level, and (3) from 0 to 5,700 feet above and 0 to 5,600 feet below sea level, the set will meet any requirement within the altitude ranges of table 10.

EXAMPLE 68.—*Principle and application of the adjustable scale*

A			B1	B2	B3	B4	B5	B6	B7
Ma	*Mi*	*si*	*ac*	*ax*	*ax*	*ax*	*ax*	*ax*	*ax*
I	−4	60.00	6,800	7,200	6,400	8,400	4,800	10,800	2,800
II	+1	59.00	6,400	6,800	6,000	8,000	4,400	10,400	2,400
		58.00	6,000	6,400	5,600	7,600	4,000	10,000	2,000
	−1	57.00	5,600	6,000	5,200	7,200	3,600	9,600	1,600
	+2	56.00	5,200	5,600	4,800	6,800	3,200	9,200	1,200
		55.00	4,800	5,200	4,400	6,400	2,800	8,800	800
		54.00	4,400	4,800	4,000	6,000	2,400	8,400	400
		53.00	4,000	4,400	3,600	5,600	2,000	8,000	0
		52.00	3,600	4,000	3,200	5,200	1,600	7,600	−400
	−2	51.00	3,200	3,600	2,800	4,800	1,200	7,200	−800
	+3	50.00	2,800	3,200	2,400	4,400	800	6,800	−1,200
		49.00	2,400	2,800	2,000	4,000	400	6,400	−1,600
	−3	48.00	2,000	2,400	1,600	3,600	0	6,000	−2,000
	+4	47.00	1,600	2,000	1,200	3,200	−400	5,600	−2,400
		46.00	1,200	1,600	800	2,800	−800	5,200	−2,800
		45.00	800	1,200	400	2,400	−1,200	4,800	−3,200
		44.00	400	800	0	2,000	−1,600	4,400	−3,600
	−4	43.00	0 *avx*	+400	−400	+1,600	−2,000	+4,000	−4,000
	+5	42.00	--------	0	--------	1,200	--------	3,600	--------
		41.00	--------	--------	--------	800	--------	3,200	--------
	−5	40.00	--------	--------	--------	400	--------	2,800	--------
	+6	39.00	--------	--------	--------	0	--------	2,400	--------
		38.00	--------	--------	--------	--------	--------	2,000	--------
		37.00	--------	--------	--------	--------	--------	1,600	--------
		36.00	--------	--------	--------	--------	--------	1,200	--------
		35.00	--------	--------	--------	--------	--------	800	--------
	−6	34.00	--------	--------	--------	--------	--------	400	--------
	+7	33.00	--------	--------	--------	--------	--------	0	--------

Example 68 serves to illustrate the method of procedure to find by the adjustable scale method the zonal colimit constants for unmodified altitudes above a given *pi* and the modified altitudes or *ax* for the same colimits as determined by a given *avx*, in which B1 *ac* altitude constants are adjusted to *pi* 43 with colimit −4+5 at sea level with colimit of major zones −I+II at 6,800 feet; B2 *ax* with *avx* +400 adjusted to the same *pi* gives the modified altitudes for the colimits 400 feet higher than the B1 constants. The other adjustments of the *avx* to the same *pi* are B3 for −400 feet, giving the colimits 400 feet lower; B4, +1,600 feet higher; B5, −2,000 feet lower; B6, +4,000 feet higher; and B7, −4,000 feet lower, than the B1 constants. Thus when a plus or minus *avx* is referred to the corresponding altitude in the adjustable scale and then adjusted to its *pi*, it gives the modified altitudes for the *pi* above or below sea level within the limits of the altitude scale; as for *pi* 43, B6, zone +7 at sea level; −6+7 at 400 feet; major −I+II at 10,800 feet above sea level; or for B7, zone −1+2 at 1,600 feet; −4+5 at −4,000 feet below sea level; and −I+II at 2,800 feet.

Thus the method of procedure is to set the B scale to the A scale at the require *avx* for a given *pi* in the *si* scale. This gives at once the *ax* for the colimits on that isophane within the range of the surface levels above the sea-level isophane. To apply to a contour map mark the positions of the modified colimits on a given isophane across the map, move the B scale and *avx* to the next isophane above or below it and proceed as before until all of the interpreted altitude colimit positions are determined and marked within the range of the altitudes above the given isophane as in figure 39. If another *pi* or quadrant has a different *avx*, adjust the B scale to the required *avx* and proceed in the same way.

If, as in figure 39, the *avx* is the same for the entire quadrant, as +200 feet, one adjustment of the B scale at +200 feet on each isophane serves to give the *ax* above it, but should the *avx* differ for different isophanes of the same quadrant, as in example 68 or for gradations as in figure 40, then the B scale is changed for each different variation and gradation.

When B is set to A for a given *avx*, it may be held in place by a rubber band until the *ax* to all the zonal colimits is marked on the map for the given isophane. Then when all of the *ax* positions are marked on each isophane of a given quadrant, they are connected by freehand lines for the colimit contours of the minor zones. The map will thus represent not only the relative colimits but also the interpreted altitude ranges of the intervening minor zones; and if desired the colimits of the zonal sections may be determined by a scale of 0.25° isophanes and 100-foot intervals as in figure 42. As a rule, however, it is sufficient to find the colimit contours of the minor zones by the 1° isophanes and 400-foot interval scales, especially on a map of a large political division; but for 0.25° quadrants or less it may be desirable to show the colimits of the zonal sections. After the zonal ranges and limits are defined by the colimit contours, the intervening minor zones may be distinctly defined by applying the adopted standard colors, as yellow for major II minor zone 4, blue for minor 3, green for minor 2, etc., or by the crosshatch method.

There are a number of other applications of the adjustable isophane-altitude scale. In fact, it will generally be more convenient to utilize it than to refer

to the table to find the *ac* and the *ax* for a given position and for the positions above and below it. Thus when the 0 in the B scale is adjusted to any given isophane it gives the altitude constants above that isophane across the given quadrant, region, or continent and when the *avx* is adjusted to a given *pi* it will give the interpreted altitudes for the zonal colimits within the area so far as represented by the *avx* for a record position or the average *avx* of two or more record positions.

INTERPRETATION BY THE TOPOGRAPHIC-PROFILE METHOD

The general principle of indicating the interpreted colimits of the zones on a topographic profile chart is the same as that of indicating them on a topographic map as described in detail under figure 43.

Figure 43 represents the surface relief across figure 39 for the elevations above sea level on isophane 43. The scale to the left gives the determined *ax* and the corresponding *IZ* (interpreted colimits of major zones —I and +II) and the minor zones and zonal sections, with the colimit altitude lines extending to the west and east slopes of the profile. To the right is a scale of *ZC* colimit zonal constants for the minor zones with colimit lines extending to the east slope 200 feet below the interpreted colimits. The contour index scale below the base isophane gives the altitude of the contours in figure 39 with vertical lines of the colimit altitudes extending to the profile lines where they intersect the altitude lines of the *ax* scale.

The method of procedure in making the profile is to take a strip of paper, place it on the given base isophane of the map, as 43 in figure 39, and mark on its upper edge the positions of the desired contours, with special marks for the colimit contours and with the corresponding altitudes entered below each contour mark as shown in figure 43. Then take a sheet of cross-section paper, say with eight lines to the inch, draw a line at the top and mark on it the longitude degrees at intervals of 0.25° as from 81.25 to 82, with vertical lines for each. Then enter the zonal and altitude scales to the left with altitude intervals of 800 feet to 1 inch above the base isophane as shown.

To find the relative positions of the contours for the profile, place the contour index scale on the base isophane and mark on it the position of the lowest altitude as 0; draw a vertical line for the base meridian from 0 to the upper border or highest altitude line. Then keeping the 0 contour of the index on the base meridian move the scale up to the 100-foot altitude line, and continue the process until all of the contour positions are marked up the east slope and down the west slope to the 3,000-foot level. When all contour positions have been marked on the corresponding altitude lines, the marks for both slopes are connected by freehand lines which represent the surface profile corresponding with the surface contours.

The profile in figure 43 is greatly exaggerated because of the radical difference between the vertical scale in feet and the horizontal scale in degrees of longitude; the *ax* vertical scale is at intervals of 800 feet to the inch while the horizontal scale is 7.5 miles to the inch, resulting in an extreme exaggeration of the angles of the profile lines.

By reference to the *ax* scale it will be noted that the colimit altitude lines for the minor zones and sections intersect the profile on the east and west slopes and thus indicate where the altitude limits may be expected, and also the ranges of the minor zones and sections between their upper and lower limits, which in scale *IZ* interpreted zones are uniformly 200 feet higher than their zonal colimit constants.

APPLICATION OF THE PROFILE PRINCIPLE TO A TOPOGRAPHIC MAP OF THE UNITED STATES

Figure 44 serves to illustrate the profile principle of representing the altitudes of the zonal colimit constants and their modified altitudes on isophane 43, represented here as a straight line across the United States. The altitudes of the *ZC* zonal constants are the same for each colimit from coast to coast and are thus represented by straight colimit lines, while the corresponding modified colimit lines are curved to represent their plus or minus variations from the constant lines and their relative positions across the continent, regardless of the surface elevations of the land, but with the altitude variation indices as determined for record altitude positions at the surface on the base isophane. The scale of *ZC* zonal colimit constants are in accordance with their altitude constants of table 10 for isophane 43, and *IZ* the interpreted zonal colimits are for the modified altitudes, and the corresponding lines for each colimit by the altitude variation index for each 1° of longitude across the continent.

The range of the altitude scale is from 11,000 feet above to 8,000 feet below sea level on isophane 43. The continuous modified colimit lines are based on the *a avx*, while the broken lines are based on the *w* and *c* *avx* to represent the —4+5 *w* and *c* colimit type of the *a* colimit. The surface profile line is determined as explained under figure 43, and the position of the modified colimit lines are determined by the *a* average *avx* for the record positions on isophane 43, in which the plus *avx* is measured on the position meridians above the colimit constant lines and the minus *avx* is measured below them. In other words, the modified colimit lines represent variations from the lines as determined and measured by the *a avx* for each 1° of longitude (more or less) as represented by record positions, in which a given *avx* applies vertically on or between the given meridians to all of the colimits.

The *a*, *w*, and *c* average altitude variation indices were computed from thermal records for positions within the 1°×1° quadrants from coast to coast on the base isophane. It will be noted that since the *avx* is the same for all colimits within a given surface quadrant, all of the modified colimit lines for the altitude indices are parallel to each other and have the same relation to their respective colimit constants as that for *a* —4+5.

The relative altitude positions of the interpreted colimit lines are given above and below the surface of the land, as represented by the profile, merely to show their relations to their constants, to each other, and to the prevailing modifying influences. The variation is measured from the intersection of the colimit constant lines on the middle meridian of each quadrant.

The higher or lower position of the variation lines relative to the constant lines, i. e., *a*, *w*, and *c* above signifies a higher and warmer than that of the requirement constant and below, a lower and colder position; and when the variation lines cross the constant line, as *x0*, it signifies that there is no variation for the quadrant and that the thermal records at that point agree with the requirement constant.

The relations of the *w* and *c* variation lines to the *a* variation, and of all three to their zonal constant line, not only indicate the type of zone but the local and regional type of climate. While the modified colimit

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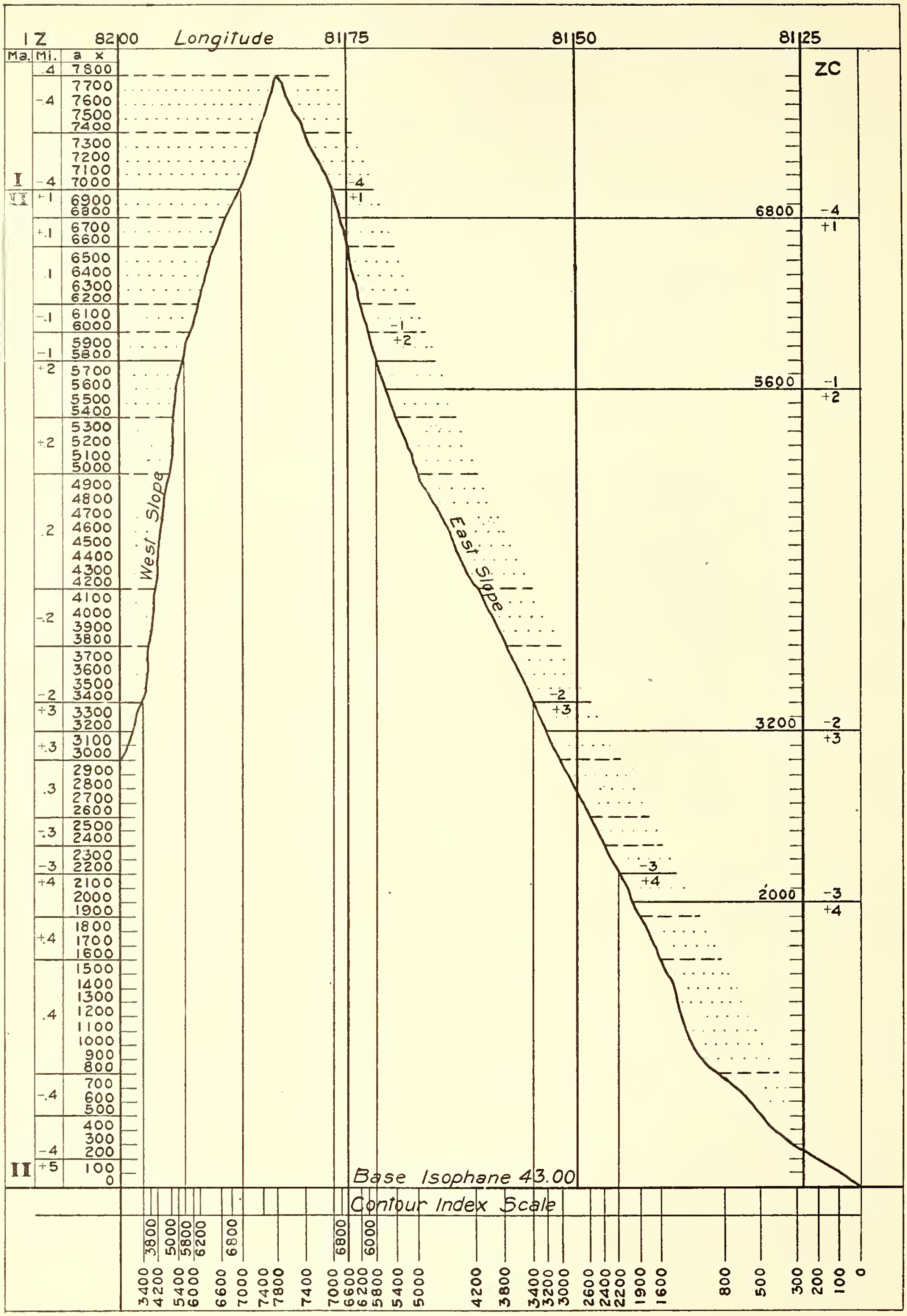
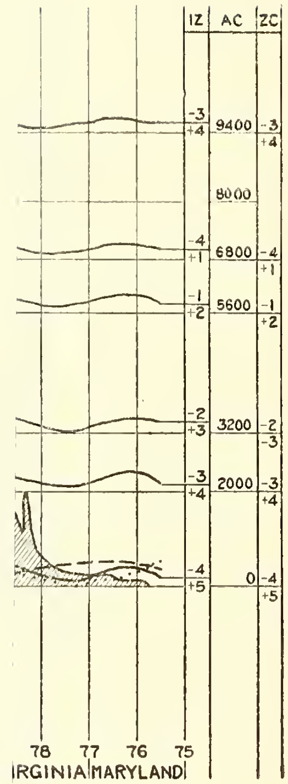


FIGURE 43.—Profile of figure 39 on base isophane 43.



IZ
AC
ZC
9400
8000
6800
5600
3200
2000
0
78
77
76
75
IRGINIA
MARYLAND

lines represent a broad general average for major regional influences, they do not represent the minor variations for minor regions and local influences as would be brought out in more detail by specific interpretations for smaller quadrants, or even more so for each record and nonrecord position.

It is obvious that a zone or type coming between two colimits can apply to the profile surface of the land only where the surface altitude comes within the given altitude range and limits of the zone represented. Thus, the *a* minor zone 4 of major II is represented on the surface between about longitudes 77 and 92; then below the surface to about longitude 117 (except for a short distance at about longitude 103 at the foot of the Black Hills in South Dakota); then on the surface between about longitudes 117 and 120 in Idaho and Washington across the Columbian basin to the east slope of the Cascades, and from the west slope across the Puget Sound region to the foot of the Olympic Mountains; then below the surface to the coast. Minor zone 3 occupies the upper middle elevations of the Allegheny Mountains from about 2,500 feet to about 3,700 feet and the surface through Iowa, Nebraska, and South Dakota from about longitude 92 at about 700 feet to longitude 103 where its upper limit is at about 4,300 feet, then across the Rocky Mountains below altitudes ranging from about 5,000 feet on the east to those below 3,000 on the west slope, then about the same on the east slope of the Cascade Mountains and between about 1,000 and 2,000 feet on the west slope, and between about 300 and 1,500 feet on the east slope and below 1,500 feet on the west slope of the Olympic Mountains on the west coast. In a like manner minor 2 occupies the higher elevations of the Allegheny Mountains and the high levels across the Rocky, Cascade, and Olympic Mountains to the timber-line zonal colimit $-1+2$, while minor 1 of major II and minor 4 of major I occupy only the higher peaks of the Rocky, Cascade, and Olympic Mountains from below to above snow line.

Significant Features

Among the more significant features brought out in this profile chart are (1) the trend of the *a* modified colimit lines to lower positions across the Great Basin and valleys and the reverse higher positions across the high plains and mountains; (2) the marked lower trend of the colimit lines from just west of the Cascade Mountains to the Pacific coast where the extreme is reached; and (3) the most significant feature of all, the relation of the *w* and *c* colimit types to the *a* colimit for $-4+5$.

While the general trend of these *w* and *c* zonal type colimit lines corresponds to the *a* zonal colimit line from east to west across the mountains, Plains, and Great Basin to about meridian 116, there are some striking exceptions across the Rocky Mountains and especially toward the Pacific coast.

The relations of the *w* and *c* lines to the *a* line and to the constant line indicate the relative intensity of the cold and heat of the *w* and *c* types of the *a* zone to be expected for all colimits within a given quadrant or region. When the *c* dotted line is below the *a* line it signifies a cold winter type, and if it is above it signifies a mild winter type. In a like manner, when the *w* line is below the *a* line it signifies a cool summer type and if above it signifies a warm or hot summer type. Two striking examples of this zonal type principle are shown by the Mississippi Basin with its warm summers and extremely cold winters thus representing a *wac* climatic type, and the Pacific coast region with its extreme cool to cold summers and extreme mild winters representing a *caw* climatic type.

It will be recognized that there are some outstanding advantages of the profile over the topographic map method as related to a single isophane: It gives a graphic picture of the vertical relations between the modified and constant ranges and limits of the minor zones, thus serving as a preliminary guide to a more detailed study and interpretation of the zones of special regions.

INTERPRETATION OF THE SEASONS AND SEASON ZONES BY RECORD THERMAL, TIME, AND DISTANCE ELEMENTS

OBJECTS, PRINCIPLES, AND METHODS

The objects to be attained from a knowledge and application of the characterizing elements of the terrestrial seasons of any region are (1) a general interpretation of the ranges and limits of the zones of the seasons by latitude, longitude, and altitude; (2) interpretation of the approximate average dates for the beginning and ending, and period in days, for each; and (3) their general character, as related to major or minor regions, areas, or specific places, by which preliminary information is made available for application to any subject on which a consideration of the influences of the seasonal factors is required. The principles of application and methods of procedure are similar to those already described and illustrated by examples and charts under the application of bioclimatic principles.

THE SEA-LEVEL ISOTHERM INDEX

The object of utilizing representative sea-level isotherms as record indices to preliminary interpretations of the seasons is to show by means of examples and charts (1) the relations between (*a*) the latitude and date limits in the poleward and equatorward movements of the monthly isotherms and (*b*) the constants of the astroterrestrial seasons, appendix table 16; (2) the relations of the poleward and equatorward record latitude limits of the monthly isotherms along the western and eastern coasts and along representative meridians of the continents to corresponding constants, as indicated by variations in degrees of latitude; (3) the relations between the dates of the equatorward and those of the poleward limits, as indicated by the date lines of figure 31; (4) the comparative latitude range and limits of the 70°, 60°, 50°, 30°, and 0° monthly isotherms along the western and eastern coasts and along representative meridians of longitude of both hemispheres; (5) the relation of the isotherms to the poleward advance of spring and summer and to the equatorward retreat of autumn and winter; and (6) the general isotherm indices to the length, type, and character of the warm and cold periods of the year along the coastal and interior meridians.

The possibility of interpretation by the monthly isotherms lies in the fact that the isotherm represents record normal temperatures for each month as reduced to sea level from record altitude positions across the continents. As stated by Bartholomew, the isotherms "must be looked upon as first approximations to a correct picture of the superficial distribution of temperature." It is found, however, that with all of its

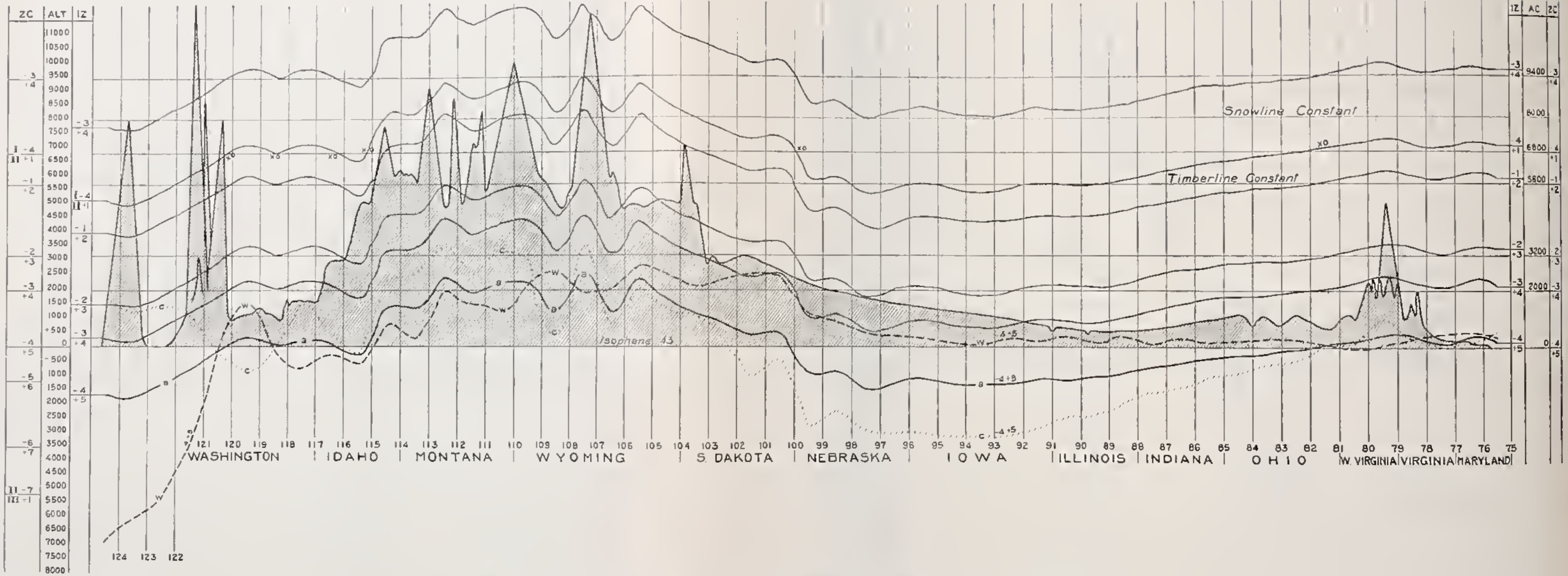


FIGURE 44.—Topographic profile across the United States on isophane 43 with interpreted limits for the *a* zone and *w* and *c* zonal types.

faults the isotherm serves as valuable evidence of the march of temperature with the corresponding movements of the seasons, as controlled by the inclination of the earth's axis and the revolution of the earth in its orbit, as shown in figure 31 and appendix table 16.

The movement of an isotherm from its equatorward latitude position in the coldest month of the year to its poleward position in the warmest month is directly correlated with the poleward and equatorward movements of the terrestrial seasons, as from the ending of winter and beginning of spring and summer at the equatorward limit of zone II of the four seasons to the ending of spring-autumn and the beginning of the next winter at the poleward limit. Thus these advance and retreat movements of the isotherms are of special interest and value as indices to the movements in time and distance of the seasons of the year in season zone II.

The method of procedure in the application of this principle is to utilize isotherm maps of the continents to find the record equatorward and poleward ranges and limits of given monthly isotherms relative to the parallels of latitude and to representative meridians of longitude, such as the west and east coast, west interior, interior, and east interior, meridians. These record ranges and limits are then compared with the requirement constant latitude range and limits for each isotherm to find the variation in latitude degrees of the record from the constant, as shown in example 69 and figures 45 and 46 (Bartholomew, Physical Atlas, vol. III).

The development of a system of isotherm range and limit constants by latitude involved a comprehensive study of the movement of given monthly isotherms on all continents. Without going into details it will be sufficient for the present purpose to show them as in example 69 under limit constants and on charts by vertical lines, as designated by *c* in figures 45 and 46.

These constants represent the general isotherm requirements of the astroterrestrial law of the seasons for their poleward and equatorward movements by latitude with the inclination of the earth's axis. Thus, assuming that all astroterrestrial conditions for each isotherm were equal, the range and limits of the movements of the isotherms *would be* as represented by the constant *c* lines, but since all conditions are far from being equal across any continent along any given parallel or meridian, it is to be expected that the actual or record range and limits will vary more or less from the requirement constants. These variations will then serve as indices to the interpretation of the corresponding latitude ranges and limits in the actual poleward and equatorward advance and retreat of the seasons.

Example 69.—*Comparison of poleward and equatorward record latitude limits of the monthly isotherms with corresponding constants to find the variations*

Isotherm	Limit Const.	North America										Eurasia									
		wc		*wi*		*i*		*ei*		*ec*		*wc*		*wi*		*i*		*ei*		*ec*	
		r	*var*	*r*	*var*	*r*	*var*	*r*	*var*	*r*	*var*	*r*	*var*	*r*	*var*	*r*	*var*	*r*	*var*	*r*	*var*
70° isotherm:																					
Poleward	50	35	−15.0	55	+5.0	51	+1.0	44	−6.0	41	−9.0	43	−7.0	50	0.0	53	+3.0	56	+6.0	42	−8.0
Equatorward	23	19	−4.0	22	−1.0	22	−1.0	25	+2.0	25	+2.0	17	−6.0	20	−3.0	22	−1.0	20	−3.0	17	−6.0
60° isotherm:																					
Poleward	60	39	−21.0	64	+4.0	57	−3.0	52	−8.0	48	−12.0	55	−5.0	64	+4.0	62	+2.0	66	+6.0	57	−3.0
Equatorward	27	25	−2.0	31	+4.0	27	.0	30	+3.0	30	+3.0	32	+5.0	30	+3.0	31	+4.0	25	−2.0	21	−6.0
50° isotherm:																					
Poleward	66.5	58	−8.5	67	+0.5	64	−2.5	58	−8.5	54	−12.5	70	+3.5	70	+3.5	68	+1.5	69	+2.5	60	−6.5
Equatorward	34	40	+6.0	40	+6.0	34	.0	33	−1.0	33	−1.0	44	+10.0	36	+2.0	35	+1.0	31	−3.0	26	−8.0
30° isotherm:																					
Poleward	55	58	+3.0	62	+7.0	55	.0	49	−6.0	50	−5.0	69	+14.0	71	+16.0	60	+5.0	56	+1.0	50	−5.0
Equatorward	40	55	+15.0	50	+10.0	40	.0	41	+1.0	42	+2.0	68	+28.0	41	+1.0	40	0.0	37	−3.0	36	−4.0
0° isotherm:																					
Poleward	58	66	+8.0	62	+4.0	58	.0	54	−4.0	60	+2.0	69	+11.0	68	+10.0	67	+9.0	59	+1.0	66	+8.0
Equatorward	50	62	+12.0	61	+11.0	50	.0	49	−1.0	51	+1.0	68	+18.0	61	+11.0	45	−5.0	45	−5.0	46	−4.0

Isotherm	Limit Const.	South America						Australia						Africa					
		wc		*i*		*ec*		*wc*		*i*		*ec*		*wc*		*i*		*ec*	
		r	*var*	*r*	*var*	*r*	*var*	*r*	*var*	*r*	*var*	*r*	*var*	*r*	*var*	*r*	*var*	*r*	*var*
70° isotherm:																			
Poleward	50	21	−29.0	40	−10.0	42	−8.0	33	−17.0	35	−15.0	37	−13.0	22	−28.0	34	−16.0	34	−16.0
Equatorward	23	4	−19.0	20	−3.0	19	−4.0	18	−5.0	19	−4.0	15	−8.0	6	−17.0	23	.0	23	.0
60° isotherm:																			
Poleward	60	40	−20.0	46	−14.0	46	−14.0	37	−23.0	40	−20.0	40	−20.0	38	−22.0	38	−22.0	38	−22.0
Equatorward	27	22	−5.0	27	0.0	25	−2.0	27	.0	26	−1.0	28	+1.0	21	−6.0	30	+3.0	30	+3.0
50° isotherm:																			
Poleward	66.5	54	−12.5	55	−11.5	55	−11.5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Equatorward	34	35	+1.0	35	+1.0	35	+1.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Example 69 shows how the latitude limit constants, record limits, and variations of the records from the limit constants for the given monthly isotherms across the continents are tabulated. *Isotherm* gives the 70°, 60°, 50°, 30°, and 0° isotherms on each continent so far as represented; *limit const.*, the poleward and equatorward *latitude limit constants* for each isotherm; *r*, the record poleward and equatorward latitude limits; and *var*, the variation in latitude degrees of the record from the same constant for *wc* west coast, *wi* western interior, *i* interior, *ei* eastern interior, and *ec* east coast for the continents.

The minus signs signify that the record limit is at a lower latitude than its constant due to colder retarding influences, and the plus signs signify that the record latitude limit is higher than its constant due to a warmer

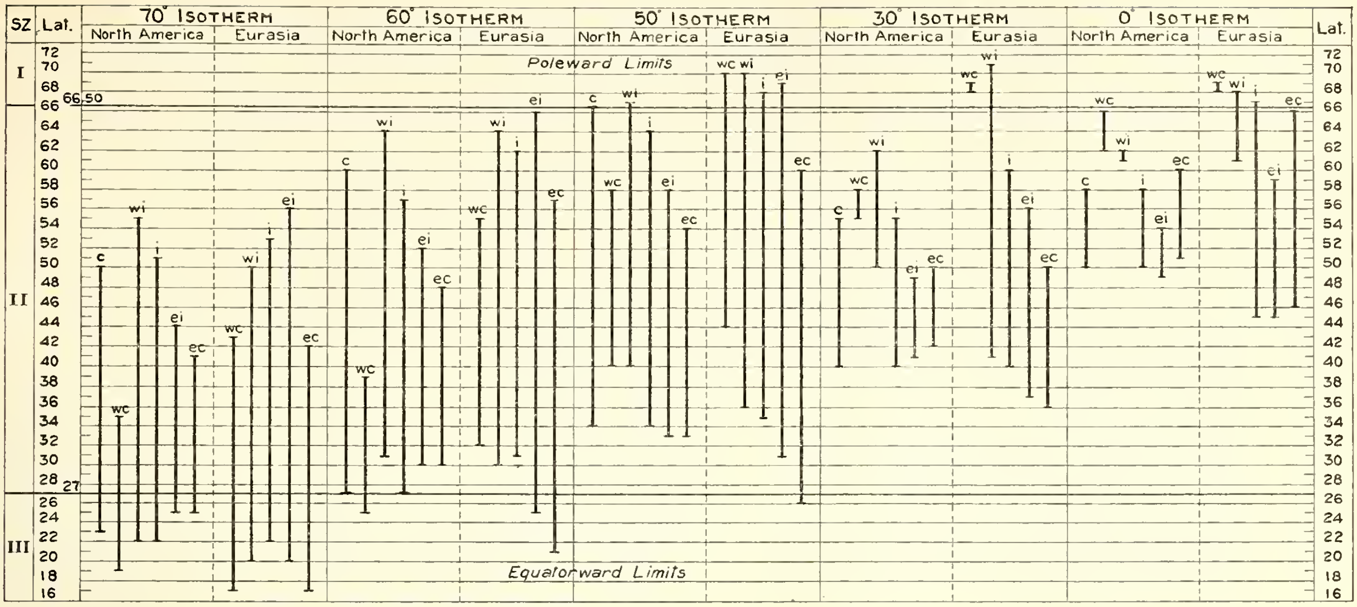


FIGURE 45.—Comparison of the constant and record latitude range and limits of the monthly isotherms of the Northern Hemisphere.

accelerating influence.[28] Thus the constant and record latitude limits are available for direct comparison or for transfer to a chart, as in figures 45 and 46.

In figure 45 the constant and record sea-level latitude range and limits of the 70°, 60°, 50°, 30°, and 0° isotherms (from example 69) are represented by vertical lines for the continents of the Northern Hemisphere. *SZ* gives the latitude range of season zone major II and part of lower majors I and upper III; *Lat.* latitude from 16° to 72° north; line *c* the sea-level latitide range and limit constants, which for each isotherm apply to all continents of the northern and southern hemispheres; while *wc* west coast, *wi* western interior, *i* interior, *ei* eastern interior, and *ec* east coast give the record latitude range and limits on each continent.

For isotherm 70°, with its equatorward limit constant in latitude 23° and its poleward limit in latitude 50°, the record equatorward limit for North America *wc* is in latitude 19° and thus 4° farther south than the requirement limit constant, which indicates a cool retarding influence; while the record poleward limit in latitude 35° is 15° farther south, which also indicates an intensified retarding influence. This indicates that the summer, as represented by the monthly mean of 70°, is relatively cool along the extreme western coast of North America, which is true. For the *wi* western interior or Rocky Mountain region, the record equatorward limit for the same isotherm is only 1° below that of the constant (i. c., it is near normal), while the record poleward limit is accelerated by a warm influence 5° farther poleward and has a greater range than its constant.

In the same way the lines of movement and limits of each isotherm in the interior and along the eastern coast are compared with their corresponding constant line and with each other in North America and Eurasia to indicate the relative retarded or accelerated movements of the corresponding seasons, as for spring and autumn by the 50° isotherm, summer by 60° and 70°, winter by 30°, and midwinter by the 0° isotherm.

The elements of figure 46 are from example 69 and are the same as in figure 45, except that the latitude given is from 4° to 66.50° south and isotherms 30° and 0° are not represented on the continents of the Southern Hemisphere. Here it will be seen that the record range is much shorter than the constant for all of the isotherms of the southern continents and that the entire record range of the 70° isotherm on the west coast of South America and Africa is equatorward from the equatorward limit of the range constant, thus indicating an extreme cool retarding influence on this isotherm along the western coasts of both continents. For the interior and east coast of South America and *wc*, *i*, and *ec* of Australia, the equatorward limits of isotherm 70° are retarded but much less so than on the west coast, while for Africa *i* and *ec* the equatorward limits are normal or in agreement with the constant.

For the 60° isotherm the retardation is much less equatorward than for the 70° isotherm, with the greatest

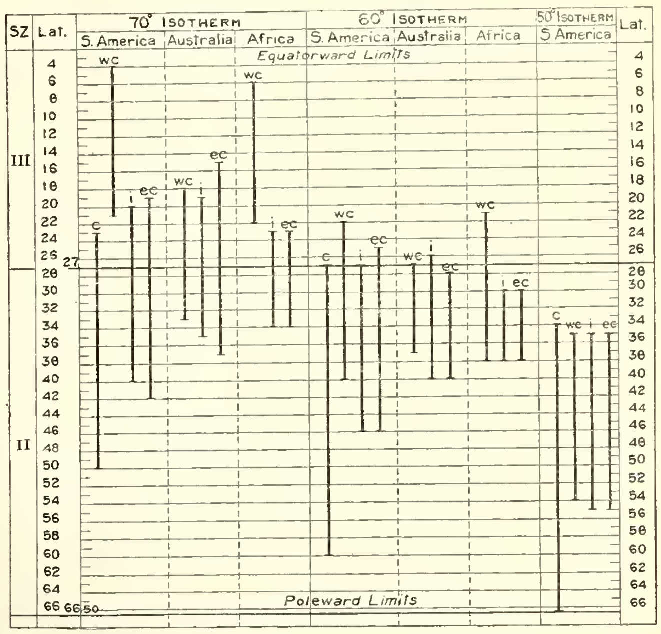


FIGURE 46.—Comparison of the constant and record latitude range and limits of the monthly isotherms of the Southern Hemisphere.

[28] Note that the minus and plus isotherm variations, as determined in this example, are the reverse of those in examples of isophane variations.

retardation for the *wc*. Also there is a greater retardation poleward, all of which indicates a decided cool retarding influence and short latitude range of the summers, as represented by the 70° and 60° isotherms.

In figure 47 the record movements and latitude limits of the isotherms for the interior of each continent—as given in example 69 and figures 45 and 46—are shown by separate lines for the 60° and 50° isotherms, and in combination for the 70°, 60°, 50°, and (additional) 40° ones. The range for each is from its equatorward to its poleward limits, with the poleward above and equatorward below for both the Northern and Southern Hemispheres. This is to show more clearly the comparative ranges and limits of each isotherm for the interior of each continent.

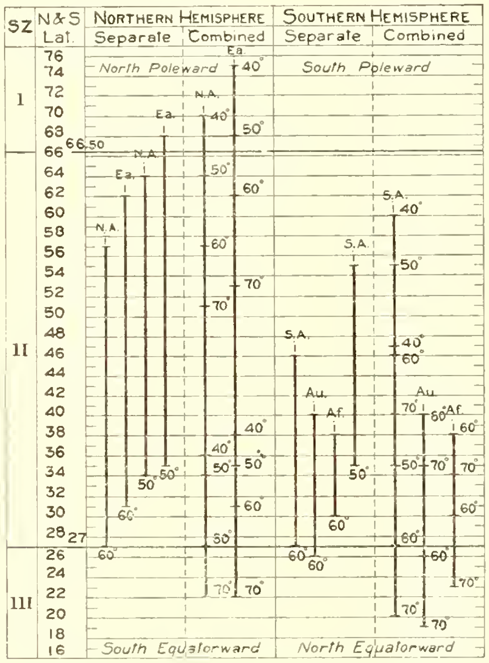


FIGURE 47.—Comparison of the poleward and equatorward movements and limits of the isotherms relative to the interior of the continents.

It will be seen in this chart, as in figures 45 and 46, that the latitude range in the movement of all of the isotherms is distinctly less on the Southern Hemisphere than on the Northern and that their corresponding poleward limits are at much lower latitudes on the Southern Hemisphere.

Figure 48 shows the movements of the record isotherms of figure 47 for the interior of the continents from their equatorward to their poleward limits by oblique range and date lines to represent their movements in time (dates of the calendar) with distance in degrees of the orbit (in the revolution of the earth) and with distance in terrestrial degrees of latitude (with the inclination of its axis), according to the principle illustrated in figures 31 and 32.

As in figure 47 the poleward and equatorward movements of the isotherms of both the Northern and Southern Hemispheres are represented in the same direction on date line 218 north and 34 south of the chart (in which each isotherm is indicated by the letters of the continent represented) and thus serve as a basis for showing the movements by the oblique date lines.

Calendars of year-dates by months are given below for the degrees of the orbit in which *north* gives the dates for the northern and *south* for the Southern Hemisphere, showing that as a rule the isotherms for the north begin their movement in January of one year and end in January of the next, while those for the south begin in July of one year and end in July of the next;[29] this provides for the earliest dates for the beginning of the advance movement of the isotherms and warm season and the latest dates for the ending of the retreat equatorward.

The median line from latitude 18° to 75° north and south gives the record poleward and equatorward limits of each isotherm and represents the general average or constant date for the warmest time of the year, as 218 north and 34 south.

The oblique range and date lines to the left or west of the median line represent the advance of the record isotherms and the warm season (with the revolution of the earth and the inclination of its axis) from their lowest equatorward limits to their highest poleward limits, and those to the right or east represent the retreat from their poleward to their equatorward limits. The advance of the isotherms corresponds to the poleward advance of the ending of the cold and beginning of the warm seasons in successively higher latitudes, while the retreat of the isotherms corresponds to the equatorward retreat to successively lower latitudes of the ending of the warm and the beginning of the cold seasons. For example, taking isotherms 40° and 50° as representing the ending of the cold and the beginning of the warm seasons, we find that the equatorward limits of isotherm 40° for *NA* is in latitude 36° and for *Ea* in latitude 38° on January 15, where its advance begins on both continents, and that on the same date the equatorward limit of isotherm 50° for *NA* is in latitude 34° and *Ea* in latitude 35°, where its advance begins. As these isotherms advance to higher latitudes and later dates in the Northern Hemisphere, *NA* 40° reaches its poleward limit in latitude 70° and *Ea* in 75°, *NA* 50° in latitude 64° and *Ea* in 68°, all on August 6, year-date 218. From this date and their relative latitude positions they begin their retreat, during which isotherm 40° for *NA* returns to latitude 36° and *Ea* to latitude 38° on January 15 of the next year, *NA* 50° to latitude 34° on December 15 (remaining in this latitude until January 15 before beginning its next advance), and *Ea* 50° returns directly to latitude 35° on January 15.

It is of special interest to note that *SA* 50° has its equatorward limit in the same latitude 35 S. as *Ea* 50° in latitude 35 N., but the advance movement for *SA* begins July 15 and the poleward limit ends February 3 in latitude 55 S., while for *Ea* the advance begins January 15 and the poleward limit is August 6 in latitude 68. In the same way the other isotherms begin their poleward movement in their respective latitudes, those of the north ending poleward on August 6 and those of the south on February 3, after which they return to their equatorward limits.

It is to be kept in mind that the record range lines, as given in this chart, represent the distance in latitude between the equatorward and poleward limits of each isotherm and therefore do not provide for the dates of the progressive movement for the intervening degrees of latitude, which would represent a zigzag or curved line by the record dates on which the isotherm *actually reaches* different latitudes. Thus the oblique straight

[29] It will be noted that there are exceptions to this rule. *Ea* 60° begins in February and ends in December; *NA* 50° ends in December; and *SA* 50°, *Af* 60°, and *Au* 60° end in June. *NA* 50° remains stationary from December to January and *Ea* 60° from December to February; while for the south they all remain stationary from June of one year to July of the next year.

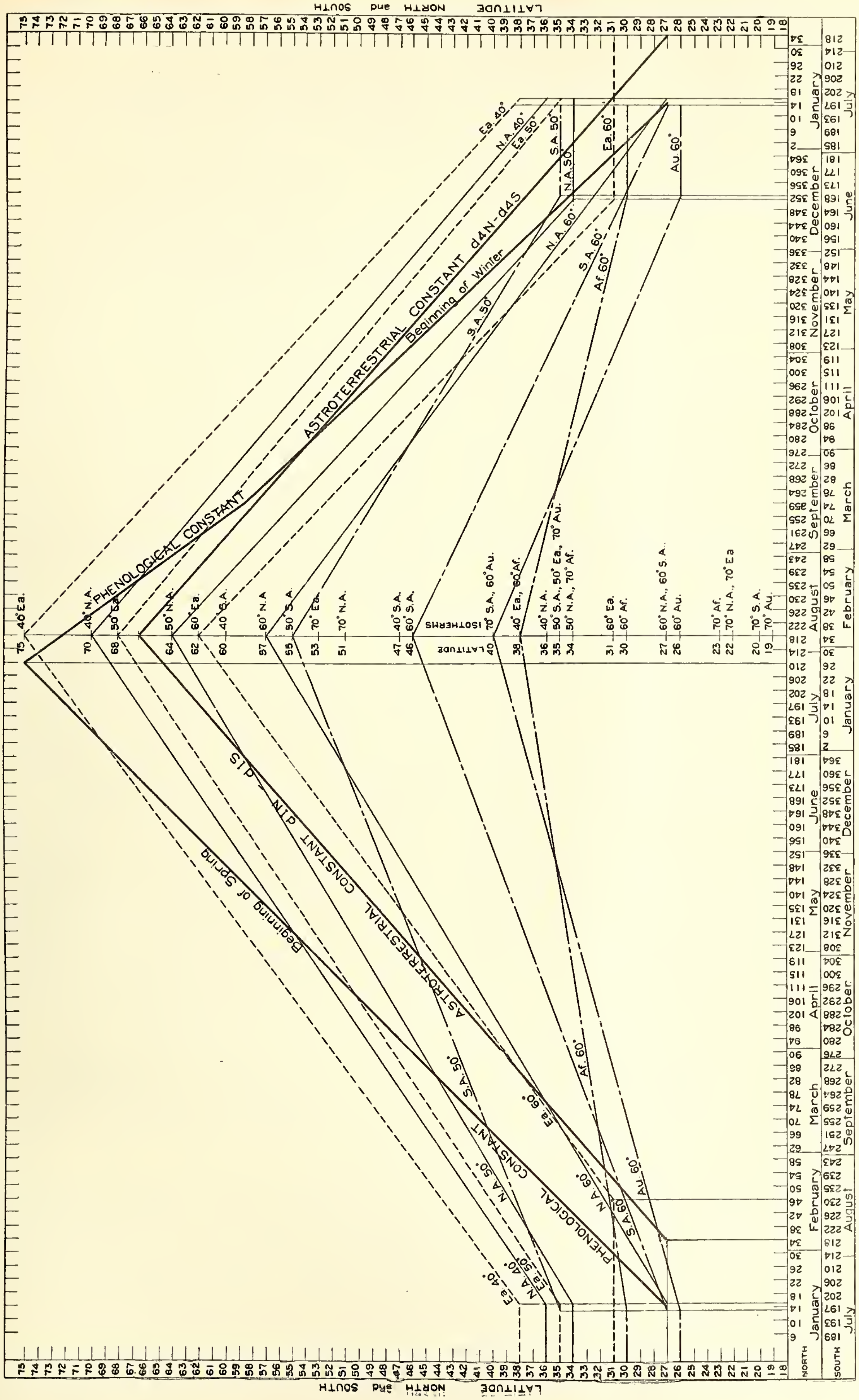


FIGURE 48.—Poleward and equatorward movements of the isotherms for the interior of the continents relative to terrestrial latitude, celestial longitude, and

line for a given isotherm simply represents the limit-to-limit trend of the records, as compared with the requirement constants for the beginning and ending of the spring-to-winter astroterrestrial and phenological seasons.

The heavy lines *d1N–d1S* and *d4N–d4S*, between latitudes 27° and 66.50° north and south represent the constant range and limit date lines for the required beginning of spring and winter of the astroterrestrial law, as in figure 31, and are given here for comparison with the record range and limit lines of the record isotherms, with special reference to isotherm 50°. For the same purpose the phenological constants for the beginning of spring and winter north, in table 9, represent the requirement constants of the bioclimatic law of the terrestrial seasons.

SIGNIFICANT FEATURES OF THE ISOTHERM INDICES

Some of the significant features brought out in example 69 and figures 45 and 46 are (1) the variations of the record latitude range and limits of the given isotherms from the requirement constants relative to the west coast, west interior, interior, east interior, and east coast of the same continent; (2) the variation of those of one continent from those of another of the same hemisphere; and (3) the difference between the range and limits of the movements of the same isotherm on the continents of the Northern and Southern Hemispheres.

It will be noted that the record latitude range and limits of the isotherms for the interior of the continents (figs. 45 and 46) come nearest to the requirement constants on the northern continents, while on the southern continents there is in general a radical difference between the requirement and the record limits. It will be noted also that for North America (fig. 45 and example 69) the greatest departure from the constant for the 70°, 60°, and 50° isotherms is along the west and east coasts, while for the 30° and 0° isotherms north the greatest departure is along the west coast and in the west interior. For Eurasia the same tendency prevails but it is here less marked than in North America, with the greatest departures on the west coast for the 30° and 0° isotherms. For the southern continents (fig. 46 and example 69) there are marked differences between the record and constant limits for the 70°, 60°, and 50° isotherms, with the greatest difference on the west coasts.

The feature of special interest is the evidence of retardation or acceleration of the movements of the record isotherms, in which a lower record latitude limit equatorward from either the poleward or equatorward limits of the constants represents retardation and prevailing colder influences, while a record limit at a higher latitude than either limit of its constant represents a warmer influence. Thus in figure 45 for North America 70° *wc*, *wi*, and *i* are retarded, while *ei* and *ec* are accelerated, relative to the equatorward limit constant; and *wc*, *ei*, and *ec* are retarded, *wi* is accelerated, and *i* is near normal, relative to the poleward limit constant.

In isotherm 30° *wc* for North America and Eurasia we find a striking example of accelerating influences of the record equatorward and poleward limits as compared with the constant limits. Thus for *NA* the record equatorward limit is accelerated by the prevailing high winter temperatures to the poleward limit of its constant, and, although its poleward limit is also accelerated, the range is only 3° between its latitude limits. For *Ea* the record equatorward and poleward limits are greatly accelerated with a range of only 1° between its limits.

In a comparative study of the constant and record ranges and limits of the isotherms on all of the continents, it will be recognized that some very interesting information is revealed on the relative intensity of the modifying influences along the coasts and different western, interior, and eastern meridians of each continent; on the very great difference in this intensity north and south of the equatorial region; and on its retarding and accelerating influence on the season, season zones, and bioclimatic phenomena.

In figure 48 the latitude range and limits of the movement of the isotherms are the same as in figure 47, but a different principle is involved in that the element of time is represented and the date and range lines of two constants are given for comparison, one representing the astroterrestrial law of the seasons and the other the bioclimatic law as related to the phenological seasons.

It is to be kept clearly in mind that the record and constant range and limits of the isotherms of the preceding charts are on a sea-level basis and, therefore, apply specifically to this base level; but since the record sea-level isotherms are computed from the lower temperature of altitude positions the modifications as determined for the corresponding sea-level position will apply alike to the altitude positions on the surface of the land above sea level (see method of computing sea-level isotherms in pt. 1).

THE *a*, *w*, AND *c* INDICES

From a detailed study of the annual, warm, and cold means relative to the astroterrestrial and terrestrial seasons, the principal results are:

1. The *a* annual mean, *w* mean of the warmest month, and *c* mean of the coldest month are the principal characterizing thermal constant elements of the astroterrestrial season zones, as they are also of the terrestrial and thermal zones, in which the given ranges of the *a*, *w*, and *c* constants of table 3 between latitudes 27° and 66.50° (north and south) represent (in the scale of zonal constants) the range of season zone II.

2. Examination of the *a*, *w*, and *c* records of only a few representative geographic positions across the continents on or near the poleward and equatorward latitude or isophane limits of season zone II (north and south) shows that there is more or less range in the variations of the records from their corresponding constants for the positions, but *it is in the variation of these records from their requirement constants of astroterrestrial or bioclimatic law* (both represented in the zonal scale of table 3) *that is found the basic key to the interpretation of the relative character and extent of the modification of the zonal constants, as characterized by the thermal elements.*

3. This is demonstrated and shown in examples and charts based on record positions across the northern and southern continents. The charts represent a new method of indicating by vertical lines the relative equivalent and record latitude and isophane positions of the *a* zonal constant and record modified zone, and of the *w* and *c* zonal types; while the examples give the *a*, *w*, and *c* variations to serve as indices to the relative intensity of the modifying influences.

4. In the representation of the record zones and types, relative to the record positions and zonal constants, the method has the advantage of giving at a

glance the essential information that is given in the corresponding examples.

5. In a comparative study of the *a* zone and *w* and *c* type constants of positions in the various continents some striking revelations appear as significant results of this method of interpreting the thermal and zonal character of the seasons to be expected at given positions around the world.

TEST EXAMPLES

In the analysis of seasons and types, the principles involved are: (1) as a rule the complex of the elements of the seasons of any two record positions in the same region will differ as the influences of the regional causation-and-factor complex differ; (2) with preliminary information on the approximate agreement in the seasonal element complex of two or more record positions, no matter how widely on the earth they may be separated, it may be assumed that in general the seasons are alike and that they represent the same season zone and zonal types; (3) with preliminary information on distinct or radical differences in the element complex of two or more record positions, no matter how near they may be in the same region, it may be assumed that their seasons are different and that they represent different zonal types; and (4) *with information on the essential seasonal elements of a place on any continent, including its minor season zones and types, the character and length of its seasons can be interpreted, and its bioclimatic features, agriculture, and economic adaptations will be indicated.*

THE THERMAL MEAN ELEMENTS

The most important of the thermal mean elements and indices utilized in the analysis of the thermal elements of the zone and zonal types of a record position are the record *a* mean for the zone, the *w* mean for the warm type, and the *c* mean for the cold type, as already discussed. The additional standard means for the interpretation of the various thermal types are those designated as *d*, *e*, *f*, *h*, and *i* of appendix table 4; *g*, the lowest recorded temperature of appendix schedule 1; the effective sum of appendix table 5; and the monthly mean indices for the beginning dates of the seasons of appendix schedule 2.

THE TIME, DATE, AND PERIOD ELEMENTS

The principal time elements of the seasons, zones, and types are (1) the date and period constants for the astroterrestrial seasons, appendix table 16; (2) the phenological seasons, appendix table 9; (3) the date constants for the latest killing frosts in spring, the earliest in autumn, and the frostless period or season, appendix table 6; (4) the thermal mean indices to the beginning dates of the seasons, appendix schedule 2; and (5) the daytime element of appendix table 15.

REPRESENTATIVE RECORD POSITIONS ACROSS NORTH AMERICA

The record positions in example 70 have been selected to represent distinctive regions across North America on or near isophane 43, with positions representing the western coast islands, Rocky Mountains, the Great Plains, the great Mississippi Basin, the Ohio Valley, the Allegheny Plateau, the Potomac Valley, and the eastern coast, each with its more or less distinctive types of climate and seasons.

EXAMPLE 70.—*List of record positions across North America on or near isophane 43*

Positions			Geographic coordinates				Equivalents		
No.	Name	State	*pl*	*plo*	*pa*	*pi*	*le*	*ei*	*el*
			°						°
1	St. Paul Island	Alaska	57.25	170	0	43.00	0.00	43.00	57.25
2	Tatoosh Island	Washington	48.25	124	100	43.25	.25	43.50	48.50
3	Buffalo	Wyoming	44.25	106	4,600	43.00	11.50	54.50	55.75
4	Tyndall	South Dakota	42.75	97	1,400	43.25	3.50	46.75	46.25
5	Lafayette	Indiana	40.25	86	600	43.00	1.50	44.50	41.75
6B	General Base Area.	West Virginia & Ohio.	39.25	81	600	43.00	1.50	44.50	40.75
6Q	Base Region	do	39.25	81	700	43.00	1.75	44.75	41.00
6K	Kanawha Farms Base.	West Virginia	39.25	81	600	43.00	1.50	44.50	40.75
6P	Parkersburg	do	39.25	81	600	43.00	1.50	44.50	40.75
6M	Marietta	Ohio	39.25	81	600	43.00	1.50	44.50	40.75
7	Terra Alta	West Virginia	39.25	79	2,600	43.50	6.50	50.00	45.75
8	Washington	District of Columbia.	38.75	77	100	43.50	.25	43.75	39.00
9	Princess Anne	Maryland	38.00	75	0	43.00	.00	43.00	38.00
10	Cape May City	New Jersey	38.75	74	0	43.75	.00	43.75	38.75

In example 70 the geographic data of the selected positions are taken from record cards in the bioclimatic files, with positions, numbers, names, State, standard symbols, etc.

Position 6B is the general base area to include 6K Kanawha Farms and the two old established meteorological stations, 6P Parkersburg and 6M Marietta, and part of the Ohio, Little Kanawha, and Muskingum Valleys, as shown in figure 8. 6Q is the base region of the 1° quadrant (fig. 7), which includes 11 meteorological stations.

EXAMPLE 71.—*Thermal, time, and precipitation records for positions in example 70*

Season elements		Positions and records													
Sym.	Subjects	1	2	3	4	5	6B	6Q	6P	6M	6K	7	8	9	10
		°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
a	Annual mean	33.4	48.4	44.4	47.2	51.0	53.1	53.3	54.0	54.2	51.1	49.1	54.9	56.0	53.2
w	Warmest month mean	46.1	55.4	68.0	74.0	74.9	74.5	74.3	75.1	75.4	72.7	69.1	76.8	76.2	73.2
c	Coldest month mean	21.2	41.1	22.7	18.8	25.6	31.8	31.9	32.6	33.0	28.4	27.8	33.7	36.7	33.6
d	Mean maximum for year	37.5	52.2	58.4	59.7	61.4	64.3	65.1	63.7	65.0	63.0	59.7	63.9	64.7	59.2
e	Mean maximum warmest month	49.4	59.7	83.0	86.8	85.9	86.2	86.8	85.4	87.0	84.0	79.8	86.4	83.9	79.0
f	Highest record	63.0	84.0	104.0	106.0	105.0	106.0	110.0	106.0	106.0	106.0	94.0	106.0	99.0	100.0
g	Lowest record	−26.0	7.0	−38.0	−41.0	−33.0	−37.0	−32.0	−27.0	−22.0	−37.0	−24.0	−15.0	−10.0	−3.0
h	Mean minimum coldest month	14.2	37.8	9.1	7.5	17.6	23.7	21.6	24.2	23.2	16.2	16.9	25.7	25.2	26.6
i	Mean minimum for year	28.3	44.7	30.4	34.7	41.1	43.7	41.5	44.3	43.2	39.3	38.5	45.9	44.9	47.1
j	Effective sum, 43° F	6.5	68.8	90.9	134.7	149.9	156.0	154.9	160.5	162.0	146.4	122.2	167.6	171.9	149.1
		Year dates	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*
S	Spring frost	169	48	149	126	115	116	118	106	109	124	132	100	111	98
A	Autumn frost	279	345	257	272	282	286	286	289	295	286	272	295	289	314
Sp	Thermal index, spring	166	15	113	97	91	84	82	82	74	91	97	82	74	91
Su	Thermal index, summer	-------	196	182	152	143	152	152	143	143	152	158	135	143	158
Au	Thermal index, autumn	-------	227	235	258	266	266	266	266	266	266	250	266	274	274
Wi	Thermal index, winter	266	349	296	305	311	314	319	319	319	319	311	327	335	327

EXAMPLE 71.—*Thermal, time, and precipitation records for positions in example 70*—Continued

Season elements		Positions and records													
Sym.	Subjects	1	2	3	4	5	6B	6Q	6P	6M	6K	7	8	9	10
		Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
P	Warm period	100	334	183	208	220	230	237	237	245	228	214	245	261	236
jp	Effective sum period	84	275	191	208	220	230	245	245	253	237	220	253	269	245
p	Frostless period	110	297	108	146	167	170	168	183	186	162	140	195	178	216
t	Precip., annual ... inches	31.35	84.08	12.03	26.01	39.01	39.78	41.28	39.14	41.22	39.00?	55.92	40.53	41.85	41.48
u	Precip., month greatest	Oct.	Dec.	May	May	May	July	July	July	July	(?)	June	July	Aug.	Aug.
	Precip ... inches	3.55	13.08	2.47	4.35	4.36	4.33	4.40	4.38	4.61	4.00	6.98	4.40	5.13	4.68
v	Precip., month least	June	July	Nov.	Jan.	Feb.	Oct.–Jan.	Nov.	Oct.	Jan.	(?)	Nov.	Nov.	Nov.	Nov.
	Precip ... inches	1.51	1.46	.42	.41	2.52	2.27	2.48	2.45	2.37	2.00	3.08	2.51	2.43	2.78
w	Precip., warm per ... do	11.60	84.08	9.34	22.30	28.02	30.93	31.35	29.59	32.31	------	36.87	31.32	32.15	26.68
y	Percent of sum of 12-hour units, daytime	65	60.7	59.6	59.1	58.6	58.0	58.0	58.0	58.0	58.0	58.0	57.5	57.5	57.5

Example 71 gives the basic record subjects for the development of a detailed analysis of the seasonal and bioclimatic features at the positions in example 70, except that the percentage of daytime is determined from the constants of appendix table 15, north.

EXAMPLE 72.—*Variations from isophane constants for positions in example 70*

Subject symbol	Appendix table	Positions and latitude-equivalent variations													
		1	2	3	4	5	6B	6Q	6P	6M	6K	7	8	9	10
a	3	+17.25	+4.75	−5.75	+2.50	+1.75	0.00	−0.50	−0.75	−0.75	+1.50	−3.75	−0.75	−0.75	+0.75
w	3	+30.00	+20.00	−6.25	−1.75	−.50	.00	.00	−.50	−1.00	+1.75	−1.50	−1.50	−.25	+2.00
c	3	+8.50	−5.25	−6.75	+6.50	+4.00	.00	−.25	−.50	−.75	+2.25	−4.25	−.50	−1.75	−.50
d	4	+23.00	+10.75	−8.00	+1.50	+2.25	.00	−1.00	+.50	−.50	+1.00	−3.25	+1.00	+1.25	+4.75
e	4	+38.25	+27.50	−9.50	−2.75	+.25	.00	−.75	+.75	−.75	+2.25	−.50	+.50	+3.75	+8.00
f	4	+37.75	+20.25	−10.75	−2.25	+1.00	.00	−4.25	.00	.00	.00	+4.00	+.75	+8.50	+6.75
h	4	+7.75	−8.50	−3.00	+8.50	+4.00	.00	+1.25	−.25	+.25	+5.00	−2.50	−.50	+.50	−1.25
i	4	+11.75	+.25	−4.00	+3.75	+1.75	.00	+1.25	−.50	+.25	+3.00	−3.50	−.75	+.75	−1.50
j	5	+31.50	+11.50	−2.50	.00	+.50	.00	−.25	−.50	−.50	+1.00	−2.00	−.50	.00	+1.50
S	6	+12.75	−10.50	−3.25	−.25	.00	.00	+.25	−2.00	−1.25	+1.75	−2.25	−2.25	+.50	−2.75
A	6	+3.25	−13.75	−2.75	+1.25	+1.00	.00	−.25	−.75	−2.25	.00	−2.00	−1.50	+.75	−6.25
Sp	9	+21.50	−15.25	−3.00	+1.00	+1.75	.00	−.75	−.50	−2.50	+1.75	−2.25	+.25	−1.00	+2.50
Su	9	----------	+11.75	−2.75	−2.25	−2.00	.00	−1.25	−2.00	−2.00	.00	−4.00	−3.00	−.50	+2.25
Au	9	----------	+10.50	−2.25	−.50	.00	.00	−.25	.00	.00	.00	−1.75	+.75	−.25	−1.00
Wi	9	+13.75	−8.00	−5.50	.00	+.75	.00	−1.50	−1.25	−1.25	−1.25	−4.75	−2.75	−4.00	−2.75
P	9	+18.00	−12.25	−4.00	+.50	+1.25	.00	−1.00	−.75	−2.00	+.25	−3.50	−1.25	−2.50	.00
jp	5	+20.25	−4.75	−5.00	+.50	+1.25	.00	−2.25	−2.00	−3.00	−1.00	−4.25	−2.25	−3.50	−1.25
p	6	+8.25	−11.50	−3.00	+.50	+.50	.00	.00	−1.25	−1.75	+1.00	−2.25	−2.00	+.50	−4.25

Example 72 gives the variations in equivalent degrees of latitude of the thermal and time records of example 71 from their corresponding isophane constants in the given appendix tables, as for *a*, *w*, and *c* in table 3; *d* to *f* and *h* and *i* in table 4; *j* and *jp* in table 5; *S*, *A*, and *p* in table 6; and *Sp*, *Su*, *Au*, *Wi*, and *P* in table 9.

For the thermal variations plus signifies a higher record isophane and *colder* and lower temperature than the position (*ei*) constant, while minus signifies a lower record isophane and *warmer* and higher temperature.

For the time subjects by year-dates, plus variations for *S*, *Sp*, and *Su* signify *colder* and *later* dates and minus the reverse, while for *A*, *Au*, and *Wi* plus signifies *colder* and earlier dates and minus the reverse. For periods, *P*, *jp*, and *p*, plus signifies *colder* and *shorter* periods, while minus signifies the reverse.

The object of the variations shown in this example is to indicate the relative intensity of the modifying warm and cold influences as measured in equivalent degrees of latitude. The purpose of expressing the variations in degrees of latitude is to make those for one subject directly comparable with those of another subject, which would not be the case if the variations were expressed in degrees Fahrenheit, for the thermal subjects and in days for the time subjects, because with different thermal and time subjects the rates differ for the same range of sea-level isophanes in their respective tables of constants.

Therefore, since the position constants for each subject are computed for the same equivalent *pi*, the difference between the *ei* and the *ri* gives a comparable variation in distance by degrees of latitude, or isophane, for any equivalent in degrees of temperature or days of time. It is to be kept in mind that 1° of latitude applies alike to the isophanes.

In a comparative study of the variations for the positions in this example, those for the different subjects in the vertical column are for the same position, while those in the horizontal series are for the same subject at all of the positions.

Thus taking position 1, St. Paul Island, the variations for all of the subjects are plus, indicating a generally colder temperature than the isophane requirement constants. Thus with the *a* variation +17.25, *w* +30, and *c* +8.50 it is plainly indicated that the warmest month is relatively much colder, and the coldest month much warmer, than the *a* average for the year, and that the position has a *caw* west-coast type of climate. This type with its relatively cool warm period is also represented by the high plus variations of the *d* mean maximum for the year, the *e* mean maximum for the warmest month, the *f* highest recorded temperature, and the *j* effective sum of the warmest months; while its mild cold period is represented by the relatively low plus variations of the *h* mean minimum of the coldest month, the *i* mean minimum for the year, and the *Wi* thermal

index to the beginning date of winter. Furthermore, the relatively low plus variations for *S* spring and *A* autumn frost dates, which represent the beginning and ending of the frostless period, indicate a relatively cool spring and fall; while for the warm periods *P*, *jp*, and *p*, all variations are (plus) cooler (and the period shorter) than the requirement constants.

Comparing the variations of position 1 with 2, 3, and 6B (the base, with no variations), the significance of the variations as indices to the relative intensity of the modifying influences and character of the seasons to be expected at each position will be strikingly apparent.

While interpretations by the variations serve as important indices to many features and elements which differentiate geographic positions and local regions, it is in the interpreted zones and zonal types that the simplest and perhaps the most reliable indices are found to the interpretation of the average seasonal features which may be expected to prevail at a given place or region, as shown in example 73 of analyzed zones, zonal types, and precipitation types.

EXAMPLE 73.—*Zones, zonal types, and precipitation types for positions in example 70*

Subject symbol	Appendix table	Positions, zones, and zonal types													
		1	2	3	4	5	6B	6Q	6P	6M	6K	7	8	9	10
zc	3	II −4+5	II −4	II .2	II +.4	II .4	II .4	II .4	II .4	II .4	II .4	II +.3	II −.4	II −4+5	II .4
a	3	I −4	II −3	−.3	.3	.4	.4	−.4	−.4	−.4	.4	.4	−4+5	+.5	−.4
w	3	I +.3	I .4	−3	.4	−.4	.4	.4	−.4	−4	.4	−.3	+.5	+5	.4
c	3	II −2	II +.6	+4	.2	−.3	.4	.4	−.4	−.4	+.4	.4	−4	.5	−4
d	4	I +4	II .2	+.4	−3	+.4	.4	−.4	.4	−.4	.4	+.4	.4	−.4	−.3
e	4	I .2	I .3	.4	−.4	.4	.4	−.4	.4	−.4	+.4	.3	−.4	+.4	−2
f	4	I .2	I .4	−.4	.4	.4	.4	−.5	.4	.4	.4	.2	.4	−2	+3
g	Schedule 1 types	−26°	+7°	−38°	−41°	−33°	−37°	−32°	−27°	−22°	−37°	−24°	−15°	−10°	−3°
h	4	II +3	II −.6	−2	+.2	−.3	.4	.4	−.4	.4	.3	+4	−4	−4	+5
i	4	II .2	II −.4	+3	+3	.4	.4	.4	−.4	.4	+4	+.4	−4+5	−.4	+.5
j	5	I +3	II +.2	−.2	+.4	.4	.4	.4	−.4	−.4	.4	−3+4	−4	−4+5	.4
S	6	II +.2	II +.7	−2	+.4	.4	.4	.4	+5	−4	.4	+4	.5	−4	.5
A	6	II .4	III +1	−2	−3+4	.4	.4	.4	−.4	+.5	.4	−3+4	+.5	−4	.6
Sp	9	I .4	III .1	−2	+4	.4	.4	−.4	−.4	+.5	.4	+4	−.4	+.5	.4
Su	9	----------	II +.2	−2	.4	+5	.4	.4	+5	+5	.4	.4	−.5	+5	.4
Au	9	----------	II .2	−.2	.4	.4	.4	.4	.4	.4	.4	−3	.4	+5	+5
Wi	9	II +2	II −.6	.3	+.4	.4	.4	−4	−4	−4	−4	.4	.5	+6	.5
P	9	I −.4	II −.7	+3	+4	.4	.4	−.4	−.4	+5	.4	+.4	+5	−.5	−.4
jp	5	I .4	II +.6	.3	+4	.4	.4	+5	+5	.5	−4	.4	.5	+6	+5
p	6	II −2	II .7	−2	+4	.4	.4	.4	−4	+5	.4	+4	.5	−4	+6
t	Schedule 3 types	31.35	84.08	12.03	26.01	39.01	39.78	41.28	39.14	41.22	39.00?	55.92	40.53	41.85	41.48
u	Schedule 3 types	Oct. 3.55	Dec. 13.08	May 2.47	May 4.35	May 4.36	July 4.33	July 4.40	July 4.38	July 4.61	? 4.00	June 6.98	July 4.40	Aug. 5.13	Aug. 4.68
v	Schedule 3 types	June 1.51	July 1.46	Nov. 0.42	Jan. 0.41	Feb. 2.52	Oct.–Jan. 2.27	Nov. 2.48	Oct. 2.45	Jan. 2.37	? 2.00	Nov. 3.08	Nov. 2.51	Nov. 2.43	Nov. 2.78
ct		caw	caw	cwa	wac	wac	awc	acw	awc	wac	awc	caw	wac	caw	caw

In this example the subject symbols are the same as those in examples 71 and 72 except that symbol *zc* gives the *a*, *w*, and *c* zonal constants from table 3, as represented by the equivalent isophane for each position. Subject *g* gives the lowest temperature types by the actual record in degrees Fahrenheit, and *t*, *u*, and *v*, the precipitation types by the records. The *a* zone and the zonal types represented by each of the other subjects are as represented by the record or the record isophane in their respective tables and scale of zonal constants and by the records alone in the schedules.

Thus, comparing the zonal constant and the record *a* zone and types by all subjects for position 1, it is seen that while the position zonal constant for *a*, *w*, and *c* is major II minor −4+5, the record *a* zone is major I minor −4, the *w* type I +.3, and the *c* type II −2. These zonal indices indicate that by the *a* zone the position is in the upper section of major season zone II, by the *w* type in zone I of perpetual winter, and by the *c* type it is in upper zone II of the four seasons. The *d* indicates the upper limit of season zone II; *e* and *f* perpetual winter types; and *g* the lowest recorded temperature −26° F. type; while by the *h* and *i* types the position is well within the northern crop zone II; and by the *j* effective sum type it is in the zone of perpetual winter. By the *S* spring frost type it is in the upper crop zone and by the *A* autumn frost type it is in the middle of the four-season crop zone; by *Sp* beginning of spring type, it is in the upper section of season zone II (*TZ*, I .4) with no summer but with a long spring-autumn growing season; by the *P* warm period type it is *TZ* I −.4; by the *jp* effective sum period type it is in the upper section of season zone II; and by the *p* frostless season type it is in the upper crop zone II.

An analysis of the precipitation shows that the *t* annual is 31.35 inches, the *u* month of greatest precipitation is October 3.55, and the *v* month of least is June 1.51 inches. The *ct* climatic type is an important element of the analysis in indicating the relatively warm or cool character of the summer or the relatively mild or cold character of the winter.

Thus, the analysis indicates that while some of the types are those of the perpetual winter season zone major I, there is a sufficient number of other types of season zone II to indicate that, under favorable soil conditions, certain hardy short-season agricultural products could be produced. It is to be kept in mind that the upper section of season zone II minor 4 is the lower section of bioclimatic zone I of the zonal constant scale of the tables of constants.

In comparing the zone and types of position 1 with those of positions 2 and 3, some striking differences will be noted as well as some remarkable agreements, e. g., in the minor zones of positions 2 and 3 in major II. The striking features of the types of position 2, Tatoosh, are in the warm winter types *c* II +.6 and *h* II −.6, and also the frost types *S* II +.7 subtropical and *A* III +1 upper tropical, with *Sp* beginning of spring type III .1 and *Wi* II −.6; while the warm temperature types *w* I .4, *e* I .3, and *f* I .4 all indicate an extreme *caw* type of climate and seasons with extremely mild winters and cool summers, with a relatively long growing season.

The zone and types of the mountain position 3, Buffalo, Wyo., are of special interest in comparison

with those of position 2. It will be noted that the *a* zone is the same and that the *j* effective sum and the *Su* and *Au* types agree quite closely, but that there is a radical difference in some of the other types. The types of special interest and significance at position 3 are those by the *c* for the coldest month, *d* mean maximum for the year, *e* mean maximum for the warmest month, and *f* highest recorded temperature; all represent major four-season zone II minor 4 types and are in general agreement with those by the same indices in the base region, but they show a striking contrast between the major II minor 2 types by the *j*, *S*, *A*, *Sp*, *Su*, *Au*, and *p* of the position and the (generally) II minor 4 types by the same indices at all of the other positions from 4 to 10.

Another feature of interest is in the *g* low temperature types of positions 3 to 6P, inclusive, as compared with those of St. Paul Island −26° below zero, all of which are much colder.

In the precipitation types we find a range in the annual of from 12.03 inches at position 3 to 84.08 at position 2. There is fairly close agreement in this type at all of the other positions, but a great difference in the months and in the amount-of-greatest-and-least-precipitation types.

THE PHENOLOGICAL INDEX ELEMENT

The dates and periods of seasonal phenomena of plants and animals and of certain farm and garden practices serve as the most important and reliable phenological indices to the beginning, progress, and length of the growing seasons of the year.

Comprehensive studies of this subject in its relation to bioclimatic law and the laws of the seasons have resulted in the development of a table of date and period constants, as appendix table 9, for the beginning of the phenological seasons at any given place on the continents of the *Northern Hemisphere*, or as table 16 for the astroterrestrial seasons on the continents of *both hemispheres*. They have also resulted in the development of a system of seasonal events of groups of plants, the average dates of which serve as indices to the beginning of the seasons of a place in any given year. By reference to the date constants of table 9 one can determine the variation each year, and the average variation for a series of years as controlled by the varying local and regional influences.

The principle of the phenological seasons is that, at any given geographic position within the zone of the four seasons, the beginning dates, progress, and duration of each season is characterized by corresponding events in the seasonal activities of certain plants and animals. In other words, plants and animals respond in their seasonal activities to the same general and specific causation-factor complex which controls and modifies the thermal elements of the local seasons.

Thus it is obvious that observed and recorded dates of representative seasonal events from year to year at a given place will serve as the best guide to the average dates of the beginning of the seasons and to the range of variation in (early and late) seasons from the average. Indeed it has been found that phenological records covering a period of 5 or more years in the same locality are far more valuable as indices to the beginning, duration, and ending of its seasons than is any thermal element or group of elements.

Unfortunately record positions where reliable series of phenological observations have been made for a sufficient number of years are exceedingly limited as compared with those where thermal and other meteorological and climatic records have been kept; but the thermal mean indices to the beginning dates of the seasons (appendix schedule 2) give a reliable system by which the dates of the beginning of each season can be interpreted, as in the following examples.

EXAMPLE 74.—*List of record positions in North America and Europe for which phenological and thermal records are available*

No.	Position	Geographic coordinates				Equivalents		
		pl	*plo*	*pa*	*pi*	*le*	*ei*	*el*
	North America:	°						°
1	Alberni, British Columbia	49.25	124 W.	300	44.25	0.75	45.00	50.00
2	Halifax, Nova Scotia	44.50	63	100	51.75	.25	52.00	44.75
6B	General Base Area, West Virginia and Ohio	39.25	81	600	43.00	1.50	44.50	40.75
8a	Washington, D. C	38.75	77	100	43.50	.25	43.75	39.00
	Europe:							
3	Tenbury, England	52.25	2	300	31.75	.75	32.50	53.00
4	Wistanstow, England	52.25	2	500	31.75	1.25	33.00	53.50
5	Berne Switzerland	46.75	7 E.	1,900	28.25	4.75	33.00	51.50
6	Brussels, Belgium	50.75	4	300	31.75	.75	32.50	51.50
7	Giessen, Germany	50.50	8	500	32.25	1.25	33.50	51.75
8	Karlsruhe, Germany	49.00	8	400	30.50	1.00	31.50	50.00
9	Stettin, Germany	53.25	14	100	36.25	.25	36.50	53.50
10	Vienna, Austria	48.00	16	700	31.25	1.75	33.00	49.75
11	Venice, Italy	45.25	12	100	27.75	.25	28.00	45.50
12	Lugano, Italy	46.00	8	900	27.75	2.25	30.00	48.25

In example 74 are included positions 1 and 2 because phenological records are here available for the beginning of spring and summer; 6B because it gives complete series of records for all seasons; and 8a because here fairly complete phenological records are available for the beginning of spring. For Europe, position 3 has complete phenological records but no thermal records, so that position 4 with its meteorological records is taken to represent the same local region; positions 5, 6, 9, and 10 have both thermal and phenological records; position 7 has phenological records for spring, summer, and autumn but no thermal, so that position 8 with its meteorological records is taken to represent the same local region; and position 12 with its meteorological data is taken to represent position 11, for which phenological records are available for the beginning of spring.

In example 75 the recorded and interpreted thermal, precipitation, phenological, and percentage of sums of 12-hour units of daytime elements are given for the positions in example 74. Under Phenological the underlined dates and periods are interpreted for the given positions by the thermal variation indices for the same or the nearest meteorological station, except that the period is the difference between the beginning phenological date for spring and the beginning thermal date for winter.

Example 76 gives the variations of the records from their isophane constants in equivalent degrees of latitude by the method as explained under example 72, except that the phenological records are referred to the date constants in table 9 to find the *ri*, which is compared with the *ei* to find the variation.

EXAMPLE 75.—*Thermal, time, and precipitation records for positions in example 74*

Sym.	Subjects	Positions and records										
		1	2	6B	8a	4	5	6	8	9	10	12
		°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
a	Annual mean	48.4	44.3	53.1	54.9	48.1	46.5	48.2	49.5	46.9	48.6	52.5
w	Warmest month mean	65.0	64.6	74.5	76.8	60.0	64.4	63.0	66.2	65.1	67.3	70.7
c	Coldest month mean	34.0	23.9	31.8	33.7	38.4	28.4	34.4	32.9	30.7	28.9	34.4
j	Effective sum, 43° F.	100.0	85.7	156.0	167.6	75.5	92.3	91.2	107.4	94.0	111.1	134.0
		Year dates	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*
Sp	Thermal index, spring	66	121	84	82	60	82	74	66	91	74	54
Su	Thermal index, summer	135	196	152	135	152	143	166	152	158	152	135
Au	Thermal index, autumn	274	227	266	266	258	266	244	250	244	258	266
Wi	Thermal index, winter	311	305	314	327	319	305	311	311	305	305	319
		Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
P	Warm period	245	184	230	245	259	223	237	245	214	231	265
jp	Effective sum period	229	192	230	253	228	214	220	229	208	214	253
t	Precipitation, annual ...inches	--------	57.3	39.78	40.53	29.91	--------	29.6	37.8	20.6	24.6	66.9
u	Precipitation month greatest	--------	Jan.	July	July	Dec.	--------	July-Aug.	June	July	May-Aug.	Nov.
	Precipitation ...inches	--------	6.0	4.33	4.40	3.30	--------	3.1	4.3	3.0	2.8	8.2
v	Precipitation month least	--------	July	Oct.-Jan.	Nov.	Sept.	--------	Apr.	Feb.	Feb.	Feb.	Feb.
	Precipitation ...inches	--------	3.7	2.27	2.51	1.92	--------	1.7	2.1	1.0	1.3	2.2
y	Percent of sum of 12-hour units, daytime	61.0	59.6	58.0	57.5	62.3	60.2	61.2	61.0	62.9	60.7	60.2
	Phenological	1	2	6B	8a	3	5	6	7	9	10	11
		Year dates	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*	*Year dates*
Sp	Phenological index, spring	72	113	84	76	64	76	61	78	83	84	41
Su	Phenological index, summer	148	182	152	135	152	143	157	154	163	154	119
Au	Phenological index, autumn	274	227	266	266	260	266	244	262	244	258	275
Wi	Phenological index, winter	311	305	314	327	319	305	311	303	305	305	326
		Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
P	Warm period	239	192	230	251	255	229	250	225	222	221	285

The outstanding features of this example are in the comparison of the variations of position 1 on the west coast of North America, position 2 on the east coast, and position 8a near the east coast with each other, with those of the European positions, and with the intercontinental base 6B. The special feature to note in thermal positions 4 to 12 (7 and 11 omitted) are the high colder (plus) variations by the *w* mean and the relatively low warmer variations by the *c* mean, thus indicating a decided *caw* type of climate and seasons for all seven of these positions and the regions represented by them. It will be seen that there is a fairly close agreement between the variations for the beginning of the seasons by the thermal and phenological indices where both are available for the same positions, e. g., 1, 2, 8a, 5, 6, 9, and 10, and also in the variations of the phenological at one, and the thermal at another, position in the same local region, as phenological 3 and thermal position 4, phenological 7 and thermal 8, and phenological 11 and thermal 12. All this indicates the reliability of the thermal index to the seasons and shows how the thermal may be checked by the phenological index wherever sufficient phenological records are available.

Under Phenological the underlined *season* variations are the differences between the *ri* and *ei* by the thermal dates and periods in example 75, while the underlined period variations are the differences between the *ri* for the period and the *ei* in appendix table 9.

EXAMPLE 76.—*Variations from isophane constants for positions in example 74*

Subject symbol	Table	Positions and latitude equivalent variations										
		1	2	6B	8a	4	5	6	8	9	10	12
a	3	+3.25	−0.50	0.00	−0.75	+15.50	+16.75	+16.00	+16.00	+13.00	+15.00	+15.00
w	3	+9.00	+2.50	.00	−1.50	+26.00	+21.50	+23.50	+21.25	+17.50	+18.75	+18.25
c	3	−2.00	−2.25	.00	−.50	+7.00	+13.75	+10.25	+12.25	+8.75	+13.50	+12.75
j	5	+5.75	+.75	.00	−.50	+21.00	+18.75	+19.50	+18.50	+15.00	+16.50	+16.75
Sp	9	−5.00	+1.50	.00	+.25	+5.50	+11.00	+9.50	+8.50	+9.75	+9.00	+7.00
Su	9	−4.25	+3.25	.00	−3.00	+11.50	+9.50	+15.50	+13.00	+9.50	+11.50	+10.75
Au	9	−2.25	+2.00	.00	+.75	+13.25	+11.50	+17.25	+16.75	+13.25	+13.25	+14.50
Wi	9	+.25	−5.25	.00	−2.75	+10.25	+13.75	+12.75	+13.75	+10.25	+13.75	+13.25
P	9	−2.50	−1.75	.00	−1.25	+7.75	+12.25	+11.00	+11.00	+10.00	+11.25	+10.00
jp	5	−.50	−2.75	.00	−2.25	+11.75	+13.50	+13.25	+13.00	+10.75	+13.50	+11.50
Phenological		1	2	6B	8a	3	5	6	7	9	10	11
Sp	9	−3.50	−0.50	0.00	−1.25	+7.00	+9.50	+6.25	+9.50	+7.75	+11.50	+5.75
Su	9	−1.50	−.25	.00	−3.00	+12.00	+9.50	+13.25	+11.50	+10.75	+12.00	+10.75
Au	9	−2.25	+2.00	.00	+.75	+13.25	+11.50	+17.25	+11.75	+13.25	+13.25	+14.50
Wi	9	+.25	−5.25	.00	−2.75	+10.75	+13.75	+12.75	+13.75	+10.25	+13.75	+13.25
P	9	−1.75	−2.75	.00	−2.00	+8.75	+11.50	+9.25	+11.50	+9.00	+12.50	+9.50

SEASONAL PERIODS

The relative length of the four seasons of a place is even more important than the average beginning dates, because the comparative length of each, in connection with the combined spring, summer, and autumn period and type of zone, *determines the types of cultivated plants which can be successfully grown.*

As has been shown in the preceding discussion, the seasonal periods come under different designations as the same basis, while the phenological period is based on the phenological records and *interpreted* dates, which come within a reasonable range of error. Comparative studies of the dates and periods for the record positions in these two examples reveal interesting information, and by the same principle and methods similar preliminary information can be determined for any record position on any continent.

Example 77.—*Seasonal periods for representative positions in example 70 across North America*

No.	Warm period			Effective sum period			Frostless period			Cold period		
	Spring	Winter	Per.	Spring	Winter	Per.	Spring	Autumn	Per.	Winter	Spring	Per.
1	June 15	Sept. 23	100	July 1	Sept. 23	84	June 18	Oct. 6	110	Sept. 23	June 15	265
2	Jan. 15	Dec. 15	334	Mar. 15	Dec. 15	275	Feb. 17	Dec. 11	297	Dec. 15	Jan. 15	31
3	Apr. 23	Oct. 23	183	Apr. 15	Oct. 23	191	May 29	Sept. 14	108	Oct. 23	Apr. 23	182
4	Apr. 7	Nov. 1	208	Apr. 7	Nov. 1	208	May 6	Sept. 29	146	Nov. 1	Apr. 7	157
5	Apr. 1	---do-----	220	Apr. 1	Nov. 7	220	Apr. 25	Oct. 9	167	Nov. 7	Apr. 1	145
6B	Mar. 25	Nov. 10	230	Mar. 25	Nov. 10	230	Apr. 26	Oct. 13	170	Nov. 10	Mar. 25	135
6Q	Mar. 23	Nov. 15	237	Mar. 15	Nov. 15	245	Apr. 28	---do-----	168	Nov. 15	Mar. 23	128
6P	---do-----	---do-----	237	---do-----	---do-----	245	Apr. 16	Oct. 16	183	---do-----	---do-----	128
6M	Mar. 15	---do-----	245	Mar. 7	---do----	253	Apr. 19	Oct. 22	186	---do----	Mar. 15	120
7	Apr. 7	Nov. 7	214	Apr. 1	Nov. 7	220	May 12	Sept. 29	140	Nov. 7	Apr. 7	151
8	Mar. 23	Nov. 23	245	Mar. 15	Nov. 23	253	Apr. 10	Oct. 22	195	Nov. 23	Mar. 23	120
9	Mar. 15	Dec. 1	261	Mar. 7	Dec. 1	269	Apr. 21	Oct. 16	178	Dec. 1	Mar. 15	104
10	Apr. 1	Nov. 23	236	Mar. 23	Nov. 23	245	Apr. 8	Nov. 10	216	Nov. 23	Apr. 1	129

Example 78.—*Seasonal periods for representative positions in North America and Europe in example 74*

No.	Warm period			Effective sum period			Cold period			Phenological period		
	Spring	Winter	Per.	Spring	Winter	Per.	Winter	Spring	Per.	Spring	Winter	Per.
NORTH AMERICA												
1	Mar. 7	Nov. 7	245	Mar. 23	Nov. 7	229	Nov. 7	Mar. 7	120	Mar. 13	Nov. 7	239
2	May 1	Nov. 1	184	Apr. 23	Nov. 1	192	Nov. 1	May 1	181	Apr. 23	Nov. 1	192
8a	Mar. 23	Nov. 23	245	Mar. 15	Nov. 23	253	Nov. 23	Mar. 23	120	Mar. 17	Nov. 23	251
EUROPE												
3										Mar. 5	Nov. 15	255
4	Mar. 1	Nov. 15	259	Apr. 1	Nov. 15	228	Nov. 15	Mar. 1	106			
5	Mar. 23	Nov. 1	223	---do-----	Nov. 1	214	Nov. 1	Mar. 23	142	Mar. 17	Nov. 1	229
6	Mar. 15	Nov. 7	237	---do-----	Nov. 7	220	Nov. 7	Mar. 15	128	Mar. 2	Nov. 7	250
7										Mar. 19	Oct. 30	225
8	Mar. 7	---do-----	245	Mar. 23	---do-----	229	---do-----	Mar. 7	120			
9	Apr. 1	Nov. 1	214	Apr. 7	Nov. 1	208	Nov. 1	Apr. 1	151	Mar. 24	Nov. 1	222
10	Mar. 15	---do-----	231	Apr. 1	---do-----	214	---do-----	Mar. 15	134	Mar. 25	Nov. 1	221
11										Feb. 10	Nov. 22	285
12	Feb. 23	Nov. 15	265	Mar. 7	Nov. 15	253	Nov. 15	Feb. 23	100			

characterized by different elements, e. g., the effective sum period between the index tes daas interpreted by the thermal indices 35°, 40°, or 43° F. (table 5); the frostless period between the latest killing frost in spring and the earliest in autumn (table 6); and the warm and cold periods of the year as determined by the thermal and phenological indices (schedule 2 and table 9).

In examples 77 and 78 the periods referred to in the preceding examples are compared and discussed in considerable detail. Example 77 is based on the record data of example 71, and example 78 is based on the record data of example 75 for the positions in example 74 with the warm, cold, and effective sum periods on

Example 79.—*Dates and periods for each of the record thermal seasons for positions in example 70*

No.	Spring			Summer			Autumn			Winter		
	md	*yd*	*rp*	*md*	*yd*	*rp*	*md*	*yd*	*rp*	*md*	*yd*	*rp*
1	June 15	166	50			(1)			50	Sept. 23	266	265
2	Jan. 15	15	181	July 15	196	31	Aug. 15	227	122	Dec. 15	349	31
3	Apr. 23	113	69	July 1	182	53	Aug. 23	235	61	Oct. 23	296	182
4	Apr. 7	97	55	June 1	152	106	Sept. 15	258	47	Nov. 1	305	157
5	Apr. 1	91	52	May 23	143	123	Sept. 23	266	45	Nov. 7	311	145
6B	Mar. 25	84	68	June 1	152	114	---do---	266	48	Nov. 10	314	135
6Q	Mar. 23	82	70	---do---	152	114	---do---	266	53	Nov. 15	319	128
7	Apr. 7	97	61	June 7	158	92	Sept. 7	250	61	Nov. 7	311	151
8	Mar. 23	82	53	May 15	135	131	Sept. 23	266	61	Nov. 23	327	120
9	Mar. 15	74	69	May 23	143	131	Oct. 1	274	61	Dec. 1	335	104
10	Apr. 1	91	67	June 7	158	116	---do---	274	53	Nov. 23	327	129

[1] Spring-autumn 100.

Example 80.—*Dates and periods for each of the record thermal seasons for positions in example 74*

NORTH AMERICA

No.	Spring			Summer			Autumn			Winter		
	md	*yd*	*rp*	*md*	*yd*	*rp*	*md*	*yd*	*rp*	*md*	*yd*	*rp*
1	Mar. 7	66	69	May 15	135	139	Oct. 1	274	37	Nov. 7	311	120
2	May 1	121	75	July 15	196	31	Aug. 15	227	78	Nov. 1	305	181
8a	Mar. 23	82	53	May 15	135	131	Sept. 23	266	61	Nov. 23	327	120
EUROPE												
4	Mar. 1	60	92	June 1	152	106	Sept. 15	258	61	Nov. 15	319	106
5	Mar. 23	82	61	May 23	143	123	Sept. 23	266	39	Nov. 1	305	142
6	Mar. 15	74	92	June 15	166	78	Sept. 1	244	67	Nov. 7	311	128
8	Mar. 7	66	86	June 1	152	98	Sept. 7	250	61	---do---	311	120
9	Apr. 1	91	67	June 7	158	86	Sept. 1	244	61	Nov. 1	305	151
10	Mar. 15	74	78	June 1	152	106	Sept. 15	258	47	---do---	305	134
12	Feb. 23	54	81	May 15	135	131	Sept. 23	266	53	Nov. 15	319	100

Examples 79 and 80 differ from examples 77 and 78 in that they give for the same positions the month and year-date for the beginning of each of the four seasons and the periods in days between the beginning dates of one and that of the succeeding, as based on the thermal mean indices, e. g., for position 1 in example 79 the time between June 15 (year-date 166) for spring and September 23 (year-date 266) for the beginning of winter gives a spring-autumn period of 100 days with no summer temperature, while at position 2 between January 15 and July 15 is a spring period of 181 days, between *yd* 196 and *yd* 227 a summer period of 31 days, between *yd* 227 and *yd* 349 an autumn period of 122 days, and between *yd* 349 of 1 year and *yd* 15 of the next a winter period of 31 days.

Example 81.—*Comparison of record thermal index periods with astroterrestrial period constants of table 16, north, and variations in days for positions in example 70*

No.	Table 16 N.	Spring			Summer			Autumn			Winter		
	el	*cp*	*trp*	*pv*	*cp*	*trp*	*pv*	*cp*	*trp*	*pv*	*cp*	*trp*	*pv*
	°												
1	57.25	29	50	+21	29	0	−29	29	50	+21	278	265	−13
2	48.50	56	181	+125	56	31	−25	56	122	+66	196	31	−165
3	55.75	34	69	+35	33	53	+20	34	61	+27	263	182	−81
4	46.25	63	55	−8	63	106	+43	64	47	−17	175	157	−18
5	41.75	77	52	−25	77	123	+46	77	45	−32	134	145	+11
6B	40.75	80	68	−12	80	114	+34	80	48	−32	125	135	+10
6Q	41.00	80	70	−10	79	114	+35	79	53	−26	127	128	+1
7	45.75	64	61	−3	65	92	+27	65	61	−4	171	151	−20
8	39.00	86	53	−33	86	131	+45	84	61	−23	109	120	+11
9	38.00	90	69	−21	89	131	+42	87	61	−26	99	104	+5
10	38.75	87	67	−20	87	116	+29	85	53	−32	107	129	+22
Astronomical periods	90–0	93	----	-----	93	----	-----	90	-----	-----	89	-----	-----

Example 82.—*Comparison of record phenological and thermal index periods with astroterrestrial period constants of table 16, north, and variations in days for positions in example 74*

No.	Table 16 N.	Spring			Summer			Autumn			Winter		
	el	*cp*	*rp*	*pv*	*cp*	*rp*	*pv*	*cp*	*rp*	*pv*	*cp*	*rp*	*pv*
	°												
1t	50.00	51	69	+18	52	139	+87	51	37	−14	211	120	−91
1p	50.00	51	76	+25	52	126	+74	51	37	−14	211	126	−85
2t	44.75	68	75	+7	68	31	−37	68	78	+10	162	181	+19
2p	44.75	68	69	+1	68	45	−23	68	78	+10	162	173	+11
8at	39.00	86	53	−33	86	131	+45	84	61	−23	109	120	+11
8ap	39.00	86	59	−27	86	131	+45	84	61	−23	109	114	+5
3p	53.00	42	88	+46	43	108	+65	41	59	+18	239	110	−129
4t	53.50	40	92	+52	41	106	+65	40	61	+21	243	106	−137
5t	51.50	47	61	+14	47	123	+76	46	39	−7	225	142	−83
5p	51.50	47	67	+20	47	123	+76	46	39	−7	225	136	−89
6t	51.50	47	92	+45	47	78	+31	46	67	+21	225	128	−97
6p	51.50	47	96	+49	47	87	+40	46	67	+21	225	115	−110
7p	51.75	46	76	+30	46	108	+62	46	41	−5	227	140	−87
8t	50.00	51	86	+35	52	98	+46	51	61	+10	211	120	−91
9t	53.50	40	67	+27	41	86	+45	40	61	+21	243	151	−92
9p	53.50	40	80	+40	41	81	+40	40	61	+21	243	143	−100
10t	49.75	52	78	+26	52	106	+54	52	47	−5	209	134	−75
10p	49.75	52	70	+18	52	104	+52	52	47	−5	209	144	−65
11p	45.50	65	78	+13	65	156	+91	65	51	−14	170	80	−90
12t	48.25	57	81	+24	57	131	+74	56	53	−3	194	100	−94

Examples 81 and 82 give *el* the equivalent latitude and *cp* the period constants from appendix table 16, north. In example 81, *trp* gives the thermal record periods for the positions in example 70, and *pv* the variations in days of *trp* from *cp*. In example 82, *rp* gives the record for the thermal and phenological periods of the North American and European positions in example 74, with *pv* the variations in days. Under *no* is given for each position number the suffix letter *t* for the thermal periods of example 80 and *p* for the phenological periods in example 83. In both examples plus signifies longer, and minus shorter, periods than the *cp* requirement constant of astroterrestrial law.

Example 83.—*Record and interpreted dates and periods for the phenological seasons for positions in example 74*

NORTH AMERICA

No.	Spring			Summer			Autumn			Winter		
	md	*yd*	*rp*	*md*	*yd*	*rp*	*md*	*yd*	*rp*	*md*	*yd*	*rp*
1	Mar. 13	72	76	May 28	148	126	Oct. 1	274	37	Nov. 7	311	126
2	Apr. 23	113	69	July 1	182	45	Aug. 15	227	78	Nov. 1	305	173
6B	Mar. 25	84	68	June 1	152	114	Sept. 23	266	48	Nov. 10	314	135
8a	Mar. 17	76	59	May 15	135	131	Sept. 23	266	61	Nov. 23	327	114
EUROPE												
3	Mar. 5	64	88	June 1	152	108	Sept. 17	260	59	Nov. 15	319	110
5	Mar. 17	76	67	May 23	143	123	Sept. 23	266	39	Nov. 1	305	136
6	Mar. 2	61	96	June 6	157	87	Sept. 1	244	67	Nov. 7	311	115
7	Mar. 19	78	76	June 3	154	108	Sept. 19	262	41	Oct. 30	303	140
9	Mar. 24	83	80	June 12	163	81	Sept. 1	244	61	Nov. 1	305	143
10	Mar. 25	84	70	June 3	154	104	Sept. 15	258	47	Nov. 1	305	144
11	Feb. 10	41	78	Apr. 29	119	156	Oct. 2	275	51	Nov. 22	326	80

Example 83 gives the record and interpreted month- and year-dates and periods in days for the phenological positions in example 74 for each of the four seasons; the interpreted year-dates by the thermal indices are underlined.

Example 84.—*Comparison of record phenological and thermal index periods with phenological period constants of table 9, and variations in days for positions in example 74*

No.	Table 9		Spring			Summer			Autumn			Winter		
	el	+3.75 *el*	*cp*	*rp*	*pv*	*cp*	*rp*	*pv*	*cp*	*rp*	*pv*	*cp*	*rp*	*pv*
	°	°												
1t	50.00	53.75	68	69	+1	38	139	+101	50	37	−13	209	120	−89
1p	50.00	53.75	68	76	+8	38	126	+88	50	37	−13	209	126	−83
2t	44.75	48.50	68	75	+7	81	31	−50	49	78	+29	167	181	+14
2p	44.75	48.50	68	69	+1	81	45	−36	49	78	+29	167	173	+6
8at	39.00	42.75	67	53	−14	130	131	+1	47	61	+14	121	120	−1
8ap	39.00	42.75	67	59	−8	130	131	+1	47	61	+14	121	114	−7
3p	53.00	56.75	69	88	+19	14	108	+94	49	59	+10	233	110	−123
4t	53.50	57.25	69	92	+23	10	106	+96	49	61	+12	237	106	−131
5t	51.50	55.25	68	61	−7	26	123	+97	51	39	−12	220	142	−78
5p	51.50	55.25	68	67	−1	26	123	+97	51	39	−12	220	136	−84
6t	51.50	55.25	68	92	+24	26	78	+52	51	67	+16	220	128	−92
6p	51.50	55.25	68	96	+28	26	87	+61	51	67	+16	220	115	−105
7p	51.75	55.50	68	76	+8	24	108	+84	51	41	−10	222	140	−82
8t	50.00	53.75	68	86	+18	38	98	+60	50	61	+11	209	120	−89
9t	53.50	57.25	69	67	−2	10	86	+76	49	61	+12	237	151	−86
9p	53.50	57.25	69	80	+11	10	81	+71	49	61	+12	237	143	−94
10t	49.75	53.50	68	78	+10	40	106	+66	50	47	−3	207	134	−73
10p	49.75	53.50	68	70	+2	40	104	+64	50	47	−3	207	144	−63
11p	45.50	49.25	69	78	+9	74	156	+82	49	51	+2	173	80	−93
12t	48.25	52.00	68	81	+13	53	131	+78	49	53	+4	195	100	−95

Example 84 gives the *el* as corrected (*el* +3.75) for reference to appendix table 9, relative to the base meridian 81 and base latitude 39.25, in order to find the *cp* period constants for comparison with the *rp* record and interpreted phenological periods of example 83 for the phenological positions, indicated by the suffix

letter *p*, and the record thermal periods of example 80 for the thermal positions, indicated by the suffix letter *t;* and *pv* gives the period variation in days of *rp* from the *cp* requirement constants of table 9.

These variations in days of the thermal records from the phenological constants are given for comparison with the variations of the phenological records from the same constants. In this comparison, the thermal positions are based on the thermal record index and thus represent modifications of the phenological requirement constants as indicated by the recorded temperature, while the variations for the phenological positions represent modifications of the same requirement constants as indicated by the phenological records.

It is assumed that the phenological record index gives a more reliable expression of the actual seasonal periods (as modified by regional and local conditions) than the thermal, because the seasonal events of plants are controlled by all of the complex elements and factors of the environment including the factor elements of climate and weather, while temperature is controlled by a much smaller number of elements of the local and regional causation-and-factor complex; and, also as indicated by a comparison of the thermal and phenological variations from the same constants in this example, the phenological record index gives in general a smaller variation than does the thermal record index for corresponding positions. Although this indicates that the phenological variations are more representative of the relative intensity of the influences of the causation-factor complex at a given position than is the thermal index, it is of special significance that the results of these comparisons, limited as they are, suggest that *the interpretation of the beginning and length of the seasons by the thermal index is sufficiently reliable to be adopted at least until phenological records are available* for a greater number and wider range of representative positions on the continents than at present.

In examples 85 and 86 the record warm and cold periods of the year as characterized by (*a*) the thermal monthly mean indices, (*b*) the effective sum, and (*c*) the frostless period (in example 85); and by (*a*), (*b*), and (*d*), the phenological periods (in example 86) are compared to find the differences between them, as (*a*) ± (*b*), (*b*) ± (*c*), (*a*) ± (*c*), and (*a*) ± (*d*), and the averages of (*a*), (*b*), and (*c*), and of (*a*), (*b*), and (*d*).

Since the differences between the given periods represent a different method of interpretation and since the principles and methods of finding the periods differ, the results are not expected to agree with those obtained by other methods except in a broad general way. The thermal period is determined from a schedule of monthly mean indices, by which the beginning dates are determined from the monthly means and the constants of table 9; the effective sum period between the index dates is determined for the thermal mean of 43° F. from constants of table 5; the frostless period indices are determined by the dates of latest spring and earliest autumn frosts and the constants of table 6; and the phenological period indices are based on the average recorded dates of representative seasonal events in plants and the constants of table 9.

EXAMPLE 85.—*Comparison of warm and cold record periods for positions in example 70*

No.	Warm season periods							Cold season periods						
	Thermal		Effective sum		Frostless		Average	Thermal		Effective sum		Frostless		Average
	a	*a±b*	*b*	*b±c*	*c*	*a±c*	*abc*	*a*	*a±b*	*b*	*b±c*	*c*	*a±c*	*abc*
1	100	+16	84	−26	110	−10	98	265	−16	281	+26	255	+10	267
2	334	+59	275	−22	297	+37	302	31	−59	90	+22	68	−37	63
3	183	−8	191	+83	108	+75	161	182	+8	174	−83	257	−75	204
4	208	0	208	+62	146	+62	187	157	0	157	−62	219	−62	178
5	220	0	220	+53	167	+53	202	145	0	145	−53	198	−53	163
6B	230	0	230	+60	170	+60	210	135	0	135	−60	195	−60	155
6Q	237	−8	245	+77	168	+69	217	128	+8	120	−77	197	−69	148
6P	237	−8	245	+62	183	+54	222	128	+8	120	−62	182	−54	143
6M	245	−8	253	+67	186	+59	228	120	+8	112	−67	179	−59	137
7	214	−6	220	+80	140	+74	191	151	+6	145	−80	225	−74	174
8	245	−8	253	+58	195	+50	231	120	+8	112	−58	170	−50	134
9	261	−8	269	+91	178	+83	236	104	+8	96	−91	187	−83	129
10	236	−9	245	+29	216	+20	232	129	+9	120	−29	149	−20	133

In example 85 it will be noted that the record warm periods for positions 4, 5, and 6B are the same for each by the thermal monthly mean indices and by the effective sum, but that there is a marked difference between the frostless season, as (*b*)±(*c*) and (*a*)±(*c*). This difference is due to the fact that the frostless period is that of tender plants, while the thermal and effective sum periods are those of the hardy or frost-resisting plants, and therefore represent the true warm period of plant activitiy.

With these principles of the (*a*), (*b*), (*c*), and (*d*) period indices in mind, a comparative study of the length of the seasons at two or more record positions reveals some very interesting and significant information. Thus, while the (*a*) and (*b*) periods in example 85 should be the same according to their constants, the record warm seasonal period for (*a*) is 16 days longer than (*b*) at position 1 and 59 days longer at position 2, and the effective sum period (*b*) is 26 days shorter than (*c*) at position 1 and 22 days shorter at position 2, while period (*a*) is 10 days shorter than (*c*) at position 1 and 37 days longer at position 2. In the same way the relative lengths of the periods are compared at the other positions. It is of special interest to note that the (*a*) and (*b*) record periods agree at positions 4, 5, and 6B, and that period (*a*) is shorter than (*b*) by 8 days at positions 3, 6Q, 6P, 6M, 8, and 9; by 6 days at position 7; and by 9 days at position 10.

Example 86.—*Comparison of warm and cold record periods for positions in example 74*

No.	Warm season periods							Cold season periods						
	Thermal		Effective sum		Phenological		Average	Thermal		Effective sum		Phenological		Average
	a	*a*±*b*	*b*	*b*±*d*	*d*	*a*±*d*	*abd*	*a*	*a*±*b*	*b*	*b*±*d*	*d*	*a*±*d*	*abd*
1	245	+16	229	−10	239	+6	238	120	−16	136	+10	126	−6	127
2	184	−8	192	0	192	−8	189	181	+8	173	0	173	+8	176
8a	245	−8	253	+2	251	−6	250	120	+8	112	−2	114	+6	115
3					255	+4						110	−4	
4	259	+31	228	−27			244	106	−31	137	+27			121
5	223	+9	214	−15	229	−6	222	142	−9	151	+15	136	+6	143
6	237	+17	220	−30	250	−13	236	128	−17	145	+30	115	+13	129
7					225	+20						140	−20	
8	245	+16	229	+4			237	120	−16	136	−4			128
9	214	+6	208	−14	222	−8	215	151	−6	157	+14	143	+8	150
10	231	+17	214	−7	221	+10	222	134	−17	151	+7	144	−10	143
11					285	−20						80	+20	
12	265	+12	253	−32			259	100	−12	112	+32			106

In example 86 the frostless period is omitted and the phenological period is added as the (*d*) period with the position numbers of example 74 and the periods as given in example 78. In example 86 the same principle is involved of comparing the (*a*), (*b*), and (*d*) periods; and those of the phenological positions 3, 7, and 11 are compared with the (*a*) and (*b*) periods of positions 4, 8, and 12. It will be noted that there is a fairly close agreement in the (*a*), (*b*), and (*d*) periods, all of which are relative to the time constants of tables 5 and 9.

The first section of figure 49 shows the relative beginning, ending, and length of the thermal seasons as based on the records in examples 71 and 79 for the positions in example 70, while the second section shows the relative beginning, ending, and length of the phenological and thermal seasons as based on the records and interpreted dates in examples 75, 80, and 83 for the positions in example 74.

This method represents the final stage in the preliminary interpretation and representation of the dates of the beginning and ending of the seasons which on the average may be expected to prevail at a given record position and (in general) within the local region represented by it. By this method the relative beginning, ending, and length of the seasons for any number of record positions are available for direct comparison. These data along with a study of (1) the variations from the requirements of astroterrestrial law and of (2) the zones and zonal types represented by the position records (in the preceding examples) give all of the essential evidence necessary for preliminary interpretations.

In this chart the horizontal index lines give the dates for each position of the ending of one and the beginning of the next season, e. g., for position 1, June 15 is the date for the ending of winter and beginning of spring, and September 23 for the ending of autumn and beginning of winter. The same dates are repeated on the lower line, so that by placing a ruler on the short index date lines the date is found for the ending of one season and the beginning of the next.

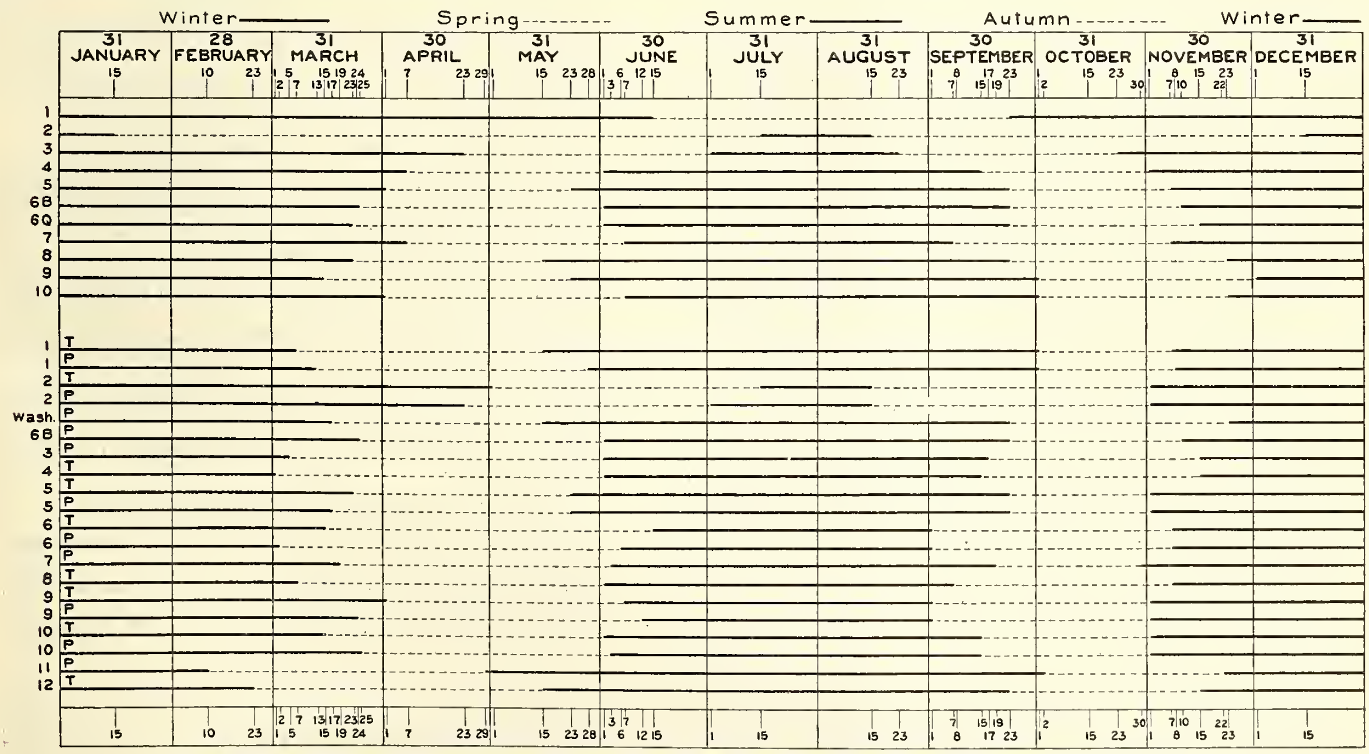


Figure 49.—Relative length of the recorded and interpreted phenological and thermal seasons for positions in examples 70 and 74.

APPLICATION OF THE MONTHLY MEAN AND PHENOLOGICAL INDICES TO THE SEASONS OF SPECIAL REGIONS AND PLACES

WEST VIRGINIA

In continued studies of the phenologic indices to the beginning of the seasons at different altitudes on or near the same isophanes, trips have been made across the State at different seasons and in different years.

The results of these studies and observations have shown that due to altitude alone there is a difference of around 30 days between the beginning of spring at Kanawha Farms at 600 feet and at the higher elevations in the Allegheny Mountains between 3,600 and 4,000 feet. It has been noted also that the observed dates at different altitudes agreed so closely with the requirement constants that the average dates could have been predicted within 7 days (2 days earlier to 5 days later), which is an allowable range of error.

Application of the thermal index to the beginning of the seasons in the same general region across the State showed (1) that by this index alone the average beginning date can be predicted for any place quite as accurately as it can be determined by actual observation, and (2) that by the phenological method the relative earliness or lateness of the seasons each year can be determined by the dates of events of certain common plants.

CINCINNATI, OHIO

The discussion of the subject of the beginning dates and length of the seasons in the preceding pages has related more specifically to averages of several years of thermal means and of dates of phenological events. Although the interpretation of the average seasons for a place is of special importance, *the variations* from the average from year to year are of the greatest significance as related to agricultural practice and other commercial interests. Thus, while the *average* may serve as a general index to general practice in a given place, specific practice relative to seed time and harvest, shipment, marketing, etc., demand more specific information on the variability of the seasons and on the range in days between early and late years to be expected within a long period of years.

As will be shown further on, if thermal records are available for a considerable number of years at one or more record positions representative of a region, it is possible to interpret by the monthly mean indices the average beginning dates and the average lengths of the seasons to be expected within the region, as well as their variability and the range between the earliest and latest, and between the longest and shortest, seasons.

To illustrate how the seasons can be interpreted for a local region by the records of long-established meteorological stations, Cincinnati, Ohio (latitude 39.00°, longitude 84°, altitude about 600 feet, and isophane 42.00), has been selected as representative of the general region of southern Ohio and the bordering sections of Kentucky and West Virginia.

The records for this station as given in Smithsonian Miscellaneous Collection volume 79, page 834, cover a consecutive period of 51 years (from 1873 to 1923, inclusive).

Interpretations were made from the monthly mean records for each year by the thermal indices of 45° F. for the beginning of spring, 66° for the beginning of summer, 64° for the beginning of autumn, and 43° for the beginning of winter. The first interpretations were made for the corresponding beginning dates of the seasons and then for the season periods between dates. From tabulated data, including averages for 51 years, the following summary of the variations of beginning dates and of length of periods from the average was prepared.

SUMMARY OF DATA ON THE SEASONS AT CINCINNATI, OHIO, BETWEEN 1873 AND 1923

Spring:

Constant beginning date, March 21, *yd* 80; period, 67 days.

Average record beginning date, March 17, *yd* 76; period, 63 days.

Variations From Average Beginning Date

Early spring seasons, 10 days or more earlier than average, 1894, 1897, 1898, 1903, 1905, 1908, 1912, 1918, and 1922 −10 days; 1878, 1907, 1910, and 1921 −16 days; and 1882 −38 days.

Late spring seasons, 10 days or more later than average, 1875, 1885, 1891, 1892, 1900, and 1906 +15 days.

Earliest spring season, 1882, Feb. 7; latest 1875, 1885, 1891, 1892, 1900, and 1906 April 1; range 53 days.

Variations From Average Period

Short spring periods, 10 days or more shorter than average, 1873, 1874, 1876, 1879, 1880, 1886, 1899, 1914, and 1916 −10 days; 1892 −11 days; 1881, 1887, and 1911 −18 days; 1875, 1900, and 1906 −19 days; and 1896 −24 days.

Long spring periods, 10 days or more longer than average, 1921 +12 days; 1894 +14 days; 1889 +15 days; 1878 +20 days; 1897 +23 days; 1910 +29 days; 1907 +35 days; and 1882 +42 days.

Shortest spring period 1896, 39 days; longest 1882, 105 days; range 66 days.

Summer:

Constant beginning date May 27, *yd* 147; period 123 days.

Average record beginning date May 19, *yd* 139; period 133 days.

Variations From Average Beginning Date

Early summer seasons, 10 days or more earlier than average, 1879, 1880, 1881, 1887, 1911, 1918, and 1922 −12 days; and 1896 −18 days.

Late summer seasons, 10 days or more later than average, 1885, 1889, 1891, 1893, 1897, 1910, and 1915 +13 days; and 1907 +19 days.

Earliest summer season 1896 May 1; latest 1907 June 7; range 37 days.

Variations From Average Period

Short summer periods, 10 days or more shorter than average, 1890, 1892, 1909, and 1917 −10 days; 1891, 1893, 1910, and 1915 −11 days; 1888 −18 days; 1885 and 1889 −19 days; and 1907 −25 days.

Long summer periods, 10 days or more longer than average, 1896 and 1919 +12 days; 1911 +15 days; 1900 and 1922 +20 days; and 1881 +28 days.

Shortest summer period 1907, 108 days; longest 1881, 161 days; range 53 days.

Autumn:

Constant beginning date September 27, *yd* 270; period 48 days.

Average record beginning date September 29, *yd* 272; period 55 days.

Variations from Average Beginning Date

Early autumn seasons, 10 days or more earlier than average 1879, 1888, and 1918−14 days.

Late autumn seasons, 10 days or more later than average, 1881, 1900, and 1919+16 days.

Earliest autumn seasons, 1879, 1888, and 1918, September 15; latest 1881, 1900, and 1919, October 15; range 30 days.

Variations from Average Period

Short autumn periods, 10 days or more shorter than average, 1873, 1880, 1886, 1891, 1892, 1893, 1894, 1898, 1904, and 1905 −10 days; 1900 and 1919 −16 days; and 1901, 1903, 1910, and 1911 −18 days.

Long autumn periods, 10 days or more longer than average, 1913 +12 days; 1888, 1890, 1896, 1902, and 1909 +14 days; 1923 +20 days; 1875, 1877, and 1879 +28 days; and 1918 +36 days.

Shortest autumn periods 1901, 1903, 1910, and 1911, 37 days; longest 1918, 91 days; range 54 days.

Winter:

Constant beginning date November 14, *yd* 318; period 127 days.

Average record beginning date November 23, *yd* 327; period 114 days.

Variations from Average Beginning Date

Early winter seasons, 10 days or more earlier than average, 1873, 1880, 1892, 1901, 1903, 1910, and 1911 −16 days.

Late winter seasons, 10 days or more later than average, 1879 and 1913 +14 days; 1875, 1881, 1918, and 1923 +22 days; and 1877 +30 days.

Earliest winter seasons, 1873, 1880, 1892, 1901, 1903, 1910, and 1911, November 7; latest 1877, December 23; range 46 days.

Variations from Average Period

Short winter periods, 10 days or more shorter than average, 1897, 1902, and 1912 −10 days; 1878, 1879, 1881, 1913, and 1923 −16 days; 1908 and 1922 −18 days; 1877 and 1921 −24 days; 1918 −32 days; and 1882 −38 days.

Long winter periods, 10 days or more longer than average, 1876, 1880, 1886, 1887, 1893, and 1904 +14 days; 1900 and 1906 +15 days; 1873, 1901, and 1911 +22 days; 1885 and 1891 +23 days; and 1892 +31 days.

Shortest winter period 1882, 76 days; longest 1892, 145 days; range 69 days.

Warm and cold periods:

Constant warm 238 days; cold 127 days.

Average record warm period 251 days; cold 114 days.

Variations from Average Warm Period

Short warm periods, 10 days or more shorter than average, 1876, 1880, 1886, 1887, 1893, and 1904 −14 days; 1900 and 1906 −15 days; 1873, 1901, and 1911 −22 days; 1885 and 1891 −23 days; and 1892 −31 days.

Long warm periods, 10 days or more longer than average, 1897, 1902, and 1912 +10 days; 1878, 1879, 1881, 1913, and 1923 +16 days; 1908 and 1922 +18 days 1877 and 1921 +24 days; 1918 +32 days and 1882 +38 days.

Shortest warm period 1892, 220 days; longest, 1882, 289 days; range 69 days.

Variations from Average Cold Period

Short cold periods, 10 days or more shorter than average, 1897, 1902, and 1912 −10 days; 1878, 1879, 1881, 1913, and 1923 −16 days; 1908 and 1922 −18 days; 1877 and 1921 −24 days; 1918 −32 days; and 1882 −38 days.

Long cold periods, 10 days or more longer than average, 1876, 1880, 1886, 1887, 1893, and 1904 +14 days; 1900 and 1906 +15 days; 1873, 1901, and 1911 +22 days; 1885 and 1891 +23 days; and 1892 +31 days.

Shortest cold period 1882, 76 days; longest 1892, 145 days; range 69 days.

The data in the summary are self explanatory in giving the constant and average record beginning dates and the length of periods for each season, and the variations in days of each season and each year from the averages, while example 87 gives the variation of the average records from the constants of appendix table 9 for the position equivalent isophane 43.50.

Example 87.—*Variations of average record beginning dates and periods from constants for Cincinnati, Ohio (equivalent isophane 43.50)*

	Spring		Summer		Autumn		Winter	
	md	*yd*	*md*	*yd*	*md*	*yd*	*md*	*yd*
Constants	Mar. 21	80	May 27	147	Sept. 27	270	Nov. 14	318
Records	Mar. 17	76	May 19	139	Sept. 29	272	Nov. 23	327
Variations in days		−4		−8		+2		+9

Example 87.—*Variations of average record beginning dates and periods from constants for Cincinnati, Ohio (equivalent isophane 43.50)*—Continued

PERIODS IN DAYS

	Spring	Summer	Autumn	Warm	Winter
Constants	67	123	48	238	127
Records	63	133	55	251	114
Variations in days	−4	+10	+7	+13	−13

Zonal constant II −4; warm period zonal type II .5.

It is to be kept in mind that a variation from the average of less than 10 days comes within a broad allowable range of error, so that in a majority of the years, as shown by the original tabulated data, the dates and periods come within this permissible range.

Thus for the beginning of spring there were 31 years, of summer 35 years, of autumn 45 years, and of winter 37 years, with plus or minus variations less than 10 days.

For the periods there is even a greater range of allowable error. For the spring period there were 35 years with plus and minus variations of 10 days or less; for summer, 33 years with variations of 6 days or less; for autumn, 34 years with variations of 10 days or less, including 12 years with minus 2 days; for winter, 23 years with variations of 8 days or less; and for the warm and cold periods there were 23 years with variations of 8 days or less.

In the variations from the requirements a somewhat smaller range of error may be allowed, but as shown in example 87 there is, in general, a remarkably close agreement between the requirement constants of bioclimatic law and the average dates and length of periods.

One of the elements of error in the interpretation of seasonal elements for a local region from the record monthly means of a meteorological station located in a city (and especially in Cincinnati located, as it is, on the banks of a large river) is the fact that such records will, as a rule, indicate earlier beginning dates of spring and summer, later beginning dates of autumn and winter, longer warm periods, and shorter cold periods, than would be indicated by records in the immediate suburb, open country, or by the constants. Thus an error of at least 4 days for the beginning and ending of the seasons, and about 8 days for the lengths of the cold and warm periods would be a reasonable allowance for the city; and by correcting the variations in example 87 for these allowable errors for the city influence, there is seen to be but little difference between the average records and the requirement constants for the position.

INTERPRETATION OF TOPOGRAPHIC TYPES OF THE MINOR ZONES

The topographic type of a given minor zone is a local lowland or highland area in which the requirement unit constant rate of the law for altitude by units of temperature and time is to some extent reversed or inverted. Thus, such a type is not only characterized by the well-known phenomena of inversion of temperature, with the lowland relatively colder, and the highland slopes and summits relatively warmer, than the thermal requirement constants of the law, but the time element is also reversed in that the warm seasons are later in spring and earlier in autumn (and consequently shorter) in the lowland than they are in the highland types, with corresponding differences in the biological features.

REVERSAL OF THE UNIT CONSTANT PRINCIPLE

While the coordinate unit constant rates and date constants of the bioclimatic law represent broad general average requirements, variation of certain positions from the constant often involves a local reversal of the standard requirements for altitude.

Thus while the standard unit constant requirements of bioclimatic law for higher altitude are lower temperature, later dates of seasonal events in spring and summer, earlier dates in autumn and winter, and shorter and colder seasons; and for lower altitude are higher temperature, earlier dates in spring and summer, later dates in autumn and winter, and longer and warmer seasons, the time or thermal records for each position may show a reversal of this principle owing to local topographic factors.

This reversal of the requirements of bioclimatic law is very important in the application of bioclimatic principles, since it represents a minor law and principle which to a certain extent are at variance with the major principles of the bioclimatic law.

THE LAW AND PRINCIPLES OF TOPOGRAPHIC INFLUENCE

The law of topographic influence is a minor law of the influence of local topography and other physiographic features on local phenomena—which is clearly represented by inversion of temperature and by corresponding reversals in seasonal and biologic phenomena from the requirements of bioclimatic law for altitude.

PRINCIPLES OF INTERPRETATION BY THE THERMAL METHOD

1. Inversions of temperature and of dates of seasonal phenomena represent the basic principles of the law of topographic influence, as manifested by thermal, time, biologic, climatic, and zonal types to a varying limit of altitude above the lowest level of a given topographic area.

2. Thermal contants are computed from the average altitude of a local area, within a range of about 1,000 feet above the lowest or base level, to represent the average constant for the area.

3. Variations of records from these constants at different levels represent the topographic influence and serve as measures of its intensity relative to the constant. These variations, especially for the recorded *a* annual, *w* warm-month, and *c* cold-month means usually show inversions, and the amount of the variation varies with the intensity of the influence which causes it and thus serves as the index to the altitude range of the warm and cold types.

4. Somewhere between the lowest and highest levels of a given area (up to a limit of about 1,000 feet above the lowest level) there is, as a rule, a belt or zone of varying width in which the average temperature is higher than that at the lowest or highest levels. These warm areas have been designated in the literature as "thermal belts", "thermal zones", "frostless zones", "verdant zones", etc., and are of great importance to fruit growers. The elevation above the lower levels at which this warmer belt occurs varies with variations in topography of each local area, but it generally occurs on the slopes and summits of the intermediate levels.

5. This law and principle of topographic influences appears to hold for all major or minor depressions and opposing elevations of land surface, including those ranging from only a few feet in vertical and horizontal distance to great continental basins and mountain ranges.

THE ALTITUDE VARIATION INDEX

In the application of bioclimatic principles to the study and interpretation of inversion types, the average *avx* for the local area or region and the position (or local) altitude variations from this index are the outstanding features because *they represent and serve to measure, in terms of feet, the relative intensity of the modified effects of the general and specific physiographic and local topographic influences.*

The altitude variation index has a decided advantage over the thermal, time, latitude, or isophane variation indices, as applied to the interpretation of inversion types, because it is directly referable to tables or charts of altitude constants, topographic maps, and specific altitude positions, by which the positions of the inversion types can be interpreted and mapped.

Thus, a plus or higher *avx* signifies a warmer inversion type than that represented by the thermal or time requirement constants for a given altitude position, and also a higher altitude position for the minor zone or zonal section, than is represented by the zonal constant for the given altitude position. In a like manner the minus or lower *avx* signifies a colder inversion type and a lower position of the zone, zonal section, and zonal type. And since there are many existing gradations in low and high land, there are many intermediate topographic types of cause and an even greater number of gradations in types of effect.

APPLICATION OF BIOCLIMATICS TO THE STUDY OF TOPOGRAPHIC TYPES IN SPECIFIC REGIONS OR AREAS

NORTH CAROLINA

RECORDS AND RECORD AREAS

The best available records for the study of topographic factor types and their effects on the inversion of temperature and related phenomena are those given by the United States Department of Agriculture.[30] Here are given tables and results of comprehensive thermal and other meteorological observations from 1913 to 1916, inclusive, in 15 local topographic areas, and at 3 to 5 record stations in each at different representative lowland and highland levels.

The thermal, distance, and time data from this source were utilized in a comprehensive study of the topographic frost and other types as related to the zones and zonal types of this region, the principal results of which are here briefly summarized.

INTERPRETATION OF INVERSION OR TOPOGRAPHIC EFFECT TYPES FOR NONRECORD POSITIONS

It was found that the variation indices, zonal types, etc., for the local record stations and record areas of Tryon, N. C., were sufficient to determine the principle and to indicate the method of procedure. With the available records of the other areas it was a simple matter to interpret the zones and types for any record position because reference of the records to a table of constants gave the desired information; but in order to interpret inversion or topographic types for local areas or specific places for which no records were available

[30] Cox, H. J. THERMAL BELTS AND FRUIT GROWING IN NORTH CAROLINA. With appendix: HUTT, W. N. THERMAL BELTS FROM THE HORTICULTURAL VIEWPOINT. U. S. Monthly Weather Rev. Sup. 19. 1923.

it was necessary to utilize determined variation indices for the nearest record position.

THE ANNUAL MEAN AS A RELIABLE INDEX

The most significant result from these studies was that the average annual mean alone serves as a reliable index to the variations to be expected within a given local area or region; and that this *a* variation index, in connection with the character of the local topography, is sufficient as a basis for preliminary interpretations of local inversion types for any given position within a record area.

THE WARM AND COLD INDICES

In addition to the annual mean, which includes an average of the heat and cold of the year as modified by regional influences, the means of the warmest and of the coldest months serve through their variation indices, relative to the *a* indices, as the most reliable indices to the type of climate represented by the local area and region.

THE MEAN MAXIMUM AND MEAN MINIMUM FOR THE YEAR, AND THE HIGHEST RECORD TEMPERATURE

While the annual mean alone, or combined with the warm and cold means, serves as a reliable index to the zone and to the zonal, climatic, and topographic types to be expected at given positions and within given areas, other thermal elements must be considered in a detailed analysis of the topographic factor and effect types. Among these the altitude variation index as determined from *d* the record mean maximum for the year, *i* the mean minimum for the year, and *f* the highest recorded temperature at a given record position referred to appendix table 4, give much information concerning certain elements of the topographic effect types.

FROST DATES AND FROSTLESS-PERIOD TYPES

From an agricultural, and especially from a fruit-growing point of view, frost dates and frostless-period types are among the more important features of any local area as related to its local topographic factor-and inversion-effect types.

PHENOLOGICAL RECORDS

The phenological data included records on the flowering dates of apple, seeding and harvest dates of winter wheat, and the average date of the first larvae of the codling moth (from Bureau of Entomology and Plant Quarantine data).

SPECIFIC RESULTS

It was shown that: (1) *The annual mean or average temperature of a place, local area, or local region is the most reliable index on which to base interpretations of the zone, zonal section, topographic effect types, and many other type features.*

2. In general the low-valley, low-broad-valley, low-narrow-valley, and low-ravine topographic factor types represent the coldest, and the middle and upper slopes and middle-to-high summits represent the warmest, effect types.

3. As a rule, the stations and subjects of each of the fifteen areas representing the coldest extreme show that the least minus (cold) variation is by the mean of the warmest month, and that the greatest minus is by the spring and autumn frosts; while for the stations representing the warmest extreme the greatest plus (warm) variation is represented by the spring and autumn frosts and the least plus (or a minus) is represented by the means of the warmest month.

4. For the area average variations the mean of the coldest month represents the warmest winter extremes, ranging for the fifteen areas from +14 days at Bryson City to +33 days longer at Asheville, with an average for the whole region of +20.1 days; while the mean of the warmest month represents the coldest summer extremes, ranging from 0 at Wilksboro to −15 days shorter at Highlands, with an average of −7.2 days. The significance of this is in the relatively warm winters and cool summers for the entire region, which thus represents a *caw* type of climate.

5. The annual mean is of the greatest value as a zonal index, and the average zonal types come close to the *a* zone. The range in *a* zone (as represented by the records of each station of an area) is from −3+4 and −.4 for Highlands to −.5 and .6 for Tryon, with minor zone 4 prevailing. This is of special significance in indicating that the average altitude of the region represents the middle of the temperature zone major II.

6. The average of the *a* variation index for the 65 record stations in 15 record areas of the North Carolina region is +9.2 days warmer than the requirement constant for the region, ranging from +7 days warmer for the Bryson City and Hendersonville areas to +14 days warmer for the Tryon area.

7. The average variation for all subjects, including *a*, is +9.3 days, ranging from +4 days for the Bryson City area and +6 days for the Hendersonville area to +12 days for the Blowing Rock area, and +13 days for the Altapass area. This comparison of averages is quite conclusive proof that the *a* variation index alone is, in general, just as reliable as any other subject or combination of subjects.

8. *The average variation index for the region is an expression (or measure) in terms of days of the relative intensity of the regional influences; the variation index for each area, compared with the regional average, is a measure of the influences of the local area; and the variation for each station, as related to the area average, is a measure of the immediate topographic and other local influences.*

9. The bioclimatic features of a local or general region may be analyzed from records of average temperature at a record position as the basic index, thus leading to interpretations of the type elements of nonrecord positions and local areas as to (*a*) the local topographic effect types of its topographic factor types; (*b*) the minor *a* zone; (*c*) the *w* and *c* zonal types, the major climatic types, and (by additional records) the seasonal type and weather types of the local nonrecord positions within the local areas; and finally (*d*) the major zonal, climatic, seasonal, weather, and biologic features of the region as a whole.

10. The regional index is in fact representative of the average of all of the record areas and evidently of all nonrecord areas. Therefore, this index of +9 days warmer can be utilized to correct the constants for nonrecord positions and areas within the region and give a local variation which will not be far from the facts. Then, by taking the local variation and correcting it for the topographic factor types, the final results as related to specific places will be near enough to the facts to form the basis for reliable preliminary interpretations of the major and many of the minor bioclimatic features of the given place or of the region as a whole. In fact, as proven by tests, they will be about as nearly correct for nonrecord positions as if they were interpreted from actual records.

11. In the interpretation of topographic effect types for nonrecord positions by variation indices based on record positions, it is important to consider the topographic factor and effect types represented by the record position or positions. If the record station is in a city, the thermal indices will be warmer than at a station at the same level located in the open country, and therefore, as a rule, corrections should be made for city stations wherever they are taken as representative of a local region.

THE SOUTHERN MOUNTAIN, COASTAL, AND GULF REGION

The study of the distinctive major and minor physiographic types of the North Carolina record area was extended to the great Atlantic Coastal Plain, southern mountain, and interior plains, regions. A topographic profile also was made along isophane 39 from longitude 77° on the Atlantic coast to 92° in the Ozark Plateau (the altitudes by the topographic map ranging from sea level to 6,700 feet) with minor zone colimit lines to show their modified altitude positions relative to the land levels along the base isophane 39. Some of the results of this study are:

1. These distinctive physiographic types are characterized by their average variations, which indicate a decidedly warmer type of climate for the coastal and mountain regions than that of the provinces westward, thus showing a progressive decrease in the intensity of the modifying influences from the coast westward into the Lexington and interior plains.
2. The major and minor types of climate that are represented by the major physiographic regions are the coastal plain, representing an eastern coast *caw* type; the central provinces, coming in the *caw* mountain type; and a moderate eastern continental *wac* type, coming between the moderate *caw* mountain and more intensive continental *wac* type.
3. The variation indices to these major climatic types are based entirely on the variation of the *a*, *w*, and *c* records from their constants.
4. The average annual mean variation index, based on 4-year average records at many local stations at different altitudes within a minor mountain region, agrees in general with the average variation indices based on the records of many more years at a large number of meteorological stations.
5. In the North Carolina region, as represented by 15 local record areas, the regional average variation index of either +9 days warmer than the requirements (or its equivalent +900 feet higher altitude) or −2.25° of equivalent lower and warmer latitude (or isophane) may be utilized to correct the date, altitude, or equivalent isophane constants to represent the regional influences. This may be supplemented by such further corrections as are indicated by the local index and the general and specific character of the local topography.
6. As shown by examples or charts (*a*) the quadrant average variation indices by the annual mean vary from east to west and from north to south across four or five different major physiographic regions; and (*b*) the major warm type increases in intensity toward the Atlantic coast and the high mountain region, then decreases westward to a transition normal type, and finally changes to a major cold winter and warm summer type which extends beyond the Mississippi River.
7. With information obtained by interpreting topographic factor types and corresponding effect types, as made available in records and publications, any intelligent fruit grower of a hilly or mountainous region should be able to locate his orchard where conditions will be favorable for its success.

TOPOGRAPHIC TYPES OF THE KANAWHA FARMS LOCAL BASE AREA

TOPOGRAPHIC FEATURES

The principal topographic features of the Kanawha Farms base area, as shown in figures 50 to 54, are the broad enclosed river valley at a general level of about 620 feet above the sea, broken by a number of ravines, and surrounded on all sides by hills rising 200 to 500 feet above the valley floor, with narrow gaps to the southwest and northwest through which the Little Kanawha River flows in its broad Butcher's Bend along the foot of the hills to the south, east, and north.

TOPOGRAPHIC FACTOR TYPES

The major topographic factor types represented by the local area and immediate surroundings, as designated by capital letters, are LL the lowland broad enclosed valley, MSL midslope, HSL highland slope, and SU summits of the hills (fig. 51).

The minor types are designated as low, middle, and high lands, with subminor types designated as lowland terraces, lowland ravines, lowland flats, low slopes, middle slopes, upper slopes, high summits, low summits, summit ridges, highland terraces or benches, and highland ravines.

The soils of the valley floor tend toward wet clay silt, and those of the hill to red clay, shale, and sandstone, with limestone near or on the higher summits and ridges.

TOPOGRAPHIC EFFECT TYPES

The topographic effect types include inversion thermal *ct* coldest, *c* cold, *wt* warmest, *w* warm, and *n* normal types relative to the topographic features and the requirement constants as in figures 51 and 52, with biologic, vegetation, ecologic, economic, cultural, hay, and grazing types of the lowland and fruit types of the highland.

PROFILE CONTOURS

The position altitude range and interrelations of the major, minor, and subminor types are shown by profiles of the relief along different base-line levels across the valley and hills.

Figure 50 shows the topographic features by 25-foot-interval contours with drainage features, and the relative position and direction of the base lines for the profiles in figures 51 and 52.

Figure 51 shows a profile along the northeast-southwest base line B of figure 50 from the southwest slope of Kanawha Hill across the river and valley to the northeast slope of Butcher Hill, with the vertical intervals of 25 feet corresponding to a horizontal interval of 500 feet on the base line. This gives an exaggerated relief, but it shows very graphically the relations between the lowland and highland and the position and vertical range of the major and minor types. The minor factor types are the general valley floor, flats, and terraces, broken by the ravines of brooklets and minor erosion.

In general there are six recognizable valley terraces as indicated by numbers in circles, including (fig. 53) terrace 1 the level of the river bottom at 600 feet as

above the sea and 20 feet *ar* above the river; terrace 2 at about 630 feet *as* and 50 feet *ar;* terrace 3 at about 655 feet *as* and 75 feet *ar;* terrace 4 at about 675 feet *as* and 95 feet *ar;* terrace 5 at about 700 feet *as* and 120 feet *ar;* and terrace 6 at about 750 feet *as* and 170 feet *ar*. These are represented by flat or gentle sloping higher levels, points, and ridges between and above the heads of the brooks and ravines leading to the less-marked flats toward the general base of Butcher Hill. The ravines up to or near the level of the terraces in which they occur are generally wooded with an association of oak, beech, hickory, black gum, and redcedar, with the tops of the large trees extending above the terraces of the general valley floor.

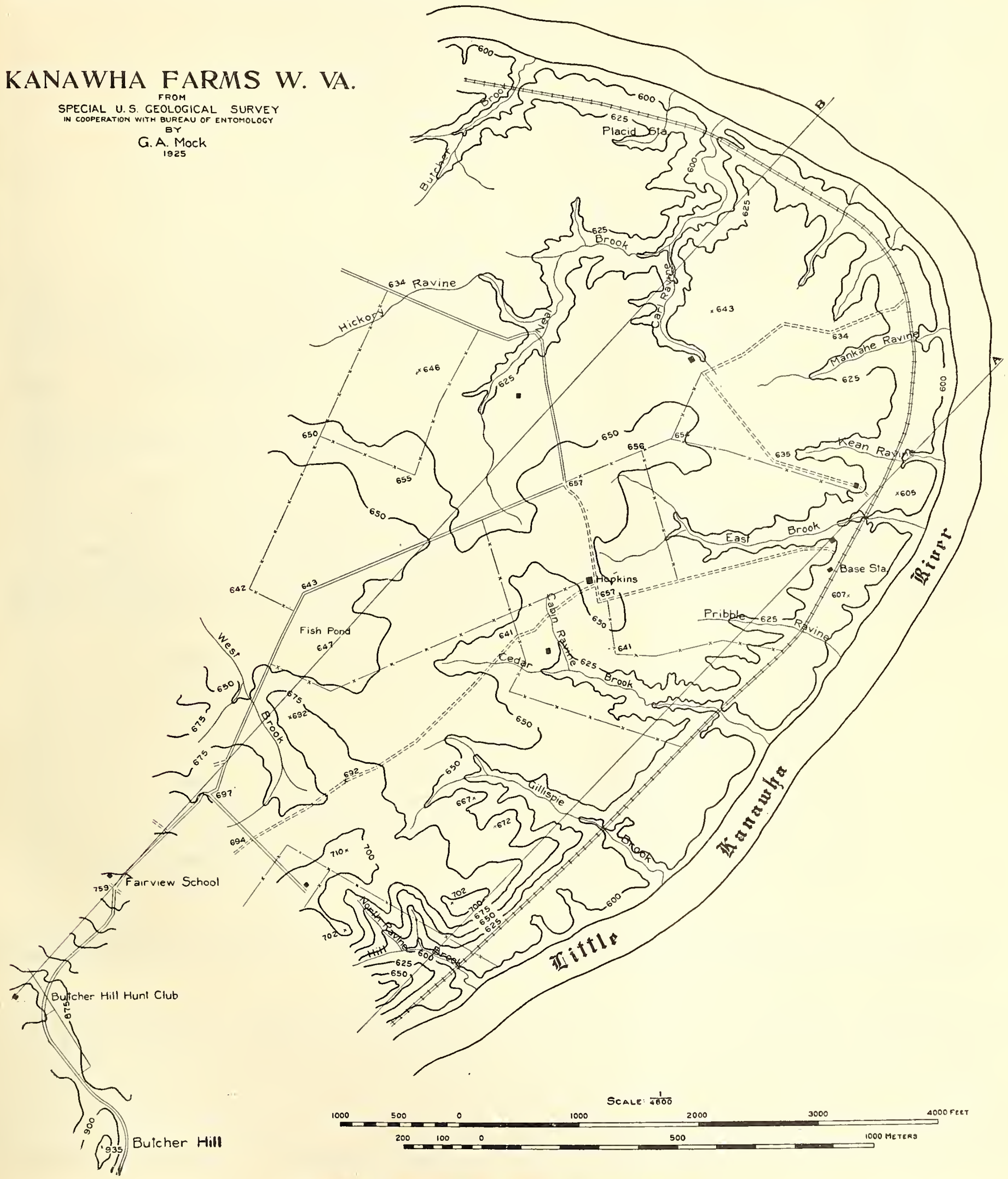


FIGURE 50.—Contour map of the Kanawha Farms Local Base Area.

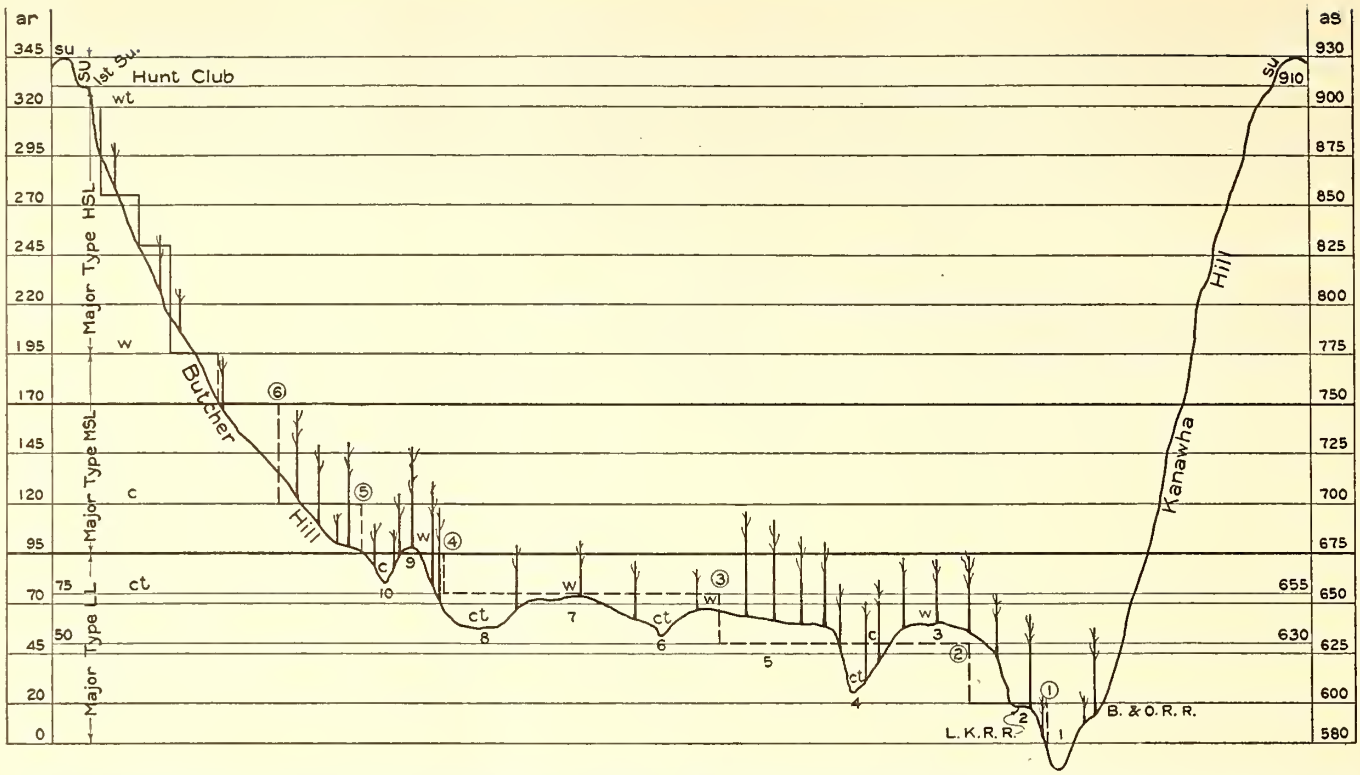


FIGURE 51.—Topographic profile across Kanawha Farms on base line B. Numerals below the profile line indicate the following: 1. Little Knawha River; 2, River Bottom; 3, Neal Field and Woods; 4, Carl Ravine; 5, Neal Grove, all on the Neal farm; 6, Head of Neal Brook on the Marsh farm; 7, Pond Park; 8, Fish or Lotus Pond; 9, Pond Point; 10 West Brook and West Woods, all on the Hopkins farm; and Butcher Hill, including the old Edmonds and Thorn farms, the Hunter's Lodge lot and the Hopkin's lot.

The hills include terraces of "benches" with "coves" at the heads of the slope ravines and are largely wooded with second-growth hardwoods and pine.

The vertical lines with short branches near the tops represent the general height and distribution of trees relative to the terraces and ravines, on the same vertical scale as the profile.

bluff. The numbers in circles designate the general level of the terraces, while those below the profile line designate other features.

The object of figure 53 is to give a generalized diagrammatic representation of the flood plains and terraces of the valley and the erosion terraces of the hills. Thus, 1 is the lowest terrace and present flood plain,

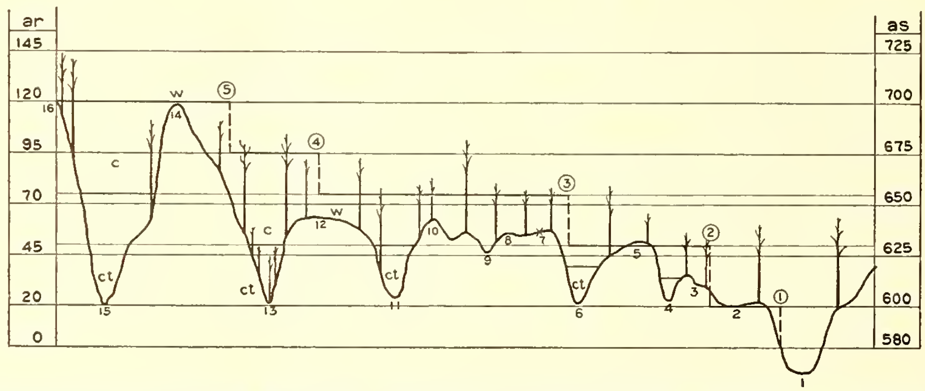


FIGURE 52.—Topographic profile across Kanawha Farms on base line A. Numerals below the profile line indicate the following: 1, River; 2, river bottom; 3, Mankahe Point 4, Kean ravine on the Neal farm; 5, Kean Point and cottage; 6, East Brook; 7, station point (with X showing the location of the base station laboratory); 8, Pribble Point; 9, Pribble ravine; 10, Cedar Point; 11, Cedar Brook and Cedar Brook woods; 12, south pasture; 13, Gillispie Brook and Gillispie Brook woods; and 14, Butcher Point, all on the Hopkins farm; 15, Hill hollow, and 16, Piney Point on the Edmonds farm.

The effect types are designated by the standard small letter symbols as *ct* coldest, *c* cool or cold, *n* normal, *wt* warmest, and *w* warm.

Figure 52 shows a profile along the northeast-southwest line A just back of the low bluffs (or points) of terraces 2 to 5. The ratio of the vertical to the horizontal scale is the same as in figure 51. The object of this profile is to show the character of the deep ravines in the terraces and their relations to the points of the

and 2, 3, 4, and 5 are the successive valley terraces and successively older flood plains. Terraces 4 and 5 represent about the upper level of the clay silt deposits, evidently from empounded water of the glacial period, while *as* 625 feet (*ar* 45 feet) represents about the level of the ancient bed of the preglacial river before it cut its way to the east and north toward the hills to form the present great bend in the river. This old river bed is indicated by a stratum of river boulders,

gravel, and sand from which perpetual springs of water flow wherever the brooks and ravines have cut down to (or below) the old river bed.

The terraces on the hill slopes (7, 8, and 9) are generalized merely to illustrate the principal rock terraces on hill and mountain slopes by strata of hard rocks of varying thickness.

The small circles (s) at about the 625-foot level represent the location of permanent springs at different places in the valley, where the brooks have cut into the old river bed, while those at about the 655-foot level flow from the base of (or between) rock strata. The water wells (ww) are at old and more recent house sites on the different terraces. Test wells for oil and gas (ow) found an inexhaustible flow of fresh water at about 75 feet and salt water at about 400 feet below the level of the first terrace. A recent well drilled on Kean Point reached this vein below a thin rock stratum at about 70 feet.

PHENOLOGICAL STUDIES

The recorded phenological dates on spring and autumn events of 16 selected tree species, and a large number of labeled early, medium, and late individuals of each species during 1915 to 1921, for spring events, and during 1915 and 1917 to 1921, for autumn events, formed the basis for a special study made on the relations of the average dates of the first general unfolding of leaves in the spring and the first general coloring of the foliage in the autumn.

Example 88.—*Altitude ranges of observation areas of the Kanawha Farms base area*

Area no.	To include—	Altitude range	100-foot intervals
9	Levels	900–930	900
8	do	800–900	800
7	do	750–800	800
6	do	700–750	700
5	Terraces 5 to 6	675–700	
4	Terraces 4 to 5	655–675	
3	Terraces 3 to 4	630–655	600
2	Gillispie ravine in terrace 2	630	
1	Terraces 1 to 2	600–630	

The location and general altitude ranges of nine observation areas including five valley terraces, a typical ravine, and three hill levels are indicated in example 88, which gives the area numbers and the range in levels and terraces included in the observations and records on which the average dates in example 89 are based, with their range in altitude above the sea relative to the nearest 100-foot level.

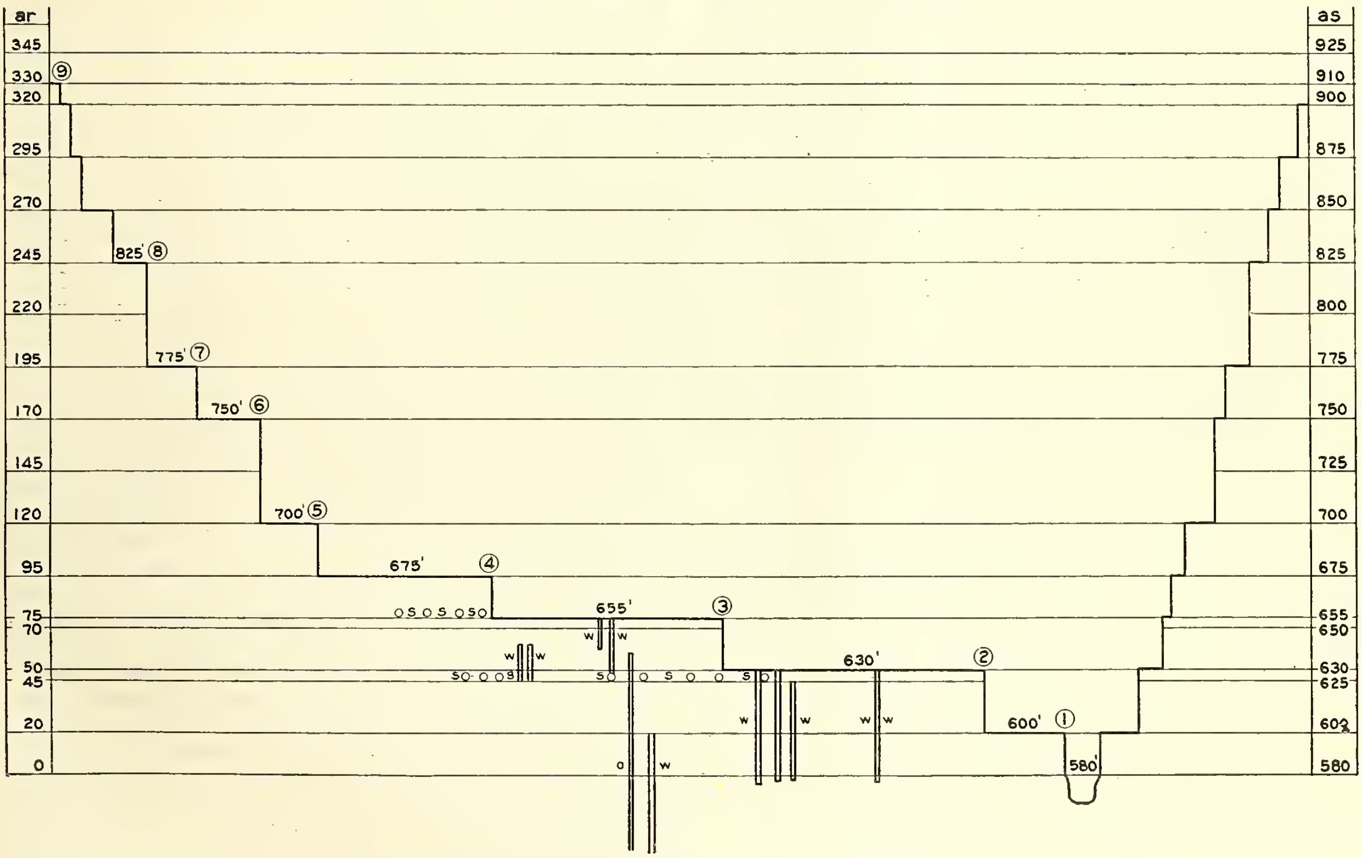


Figure 53.—Diagrammatic profile across Kanawha Farms.

EXAMPLE 89.—*Phenological spring and autumn year date, period, and zonal constants for the Kanawha Farms local base area*

pa÷4	*le*	*ei*	*Spring, yd*	*Autumn, yd*	*Period, days*	*Zonal constant*
1, 400	3. 50	46. 50	134	262	128	+. 4
1, 300	3. 25	46. 25	133	263	130	. 4
1, 200	3. 00	46. 00	132	264	132	. 4
1, 100	2. 75	45. 75	131	265	134	. 4
1, 000	2. 50	45. 50	130	266	136	. 4
900	2. 25	45. 25	129	267	138	. 4
800	2. 00	45. 00	128	268	140	. 4
B 700	1. 75	44. 75	127	269	142	. 4
600	1. 50	44. 50	126	270	144	. 4
500	1. 25	44. 25	125	271	146	−. 4
400	1. 00	44. 00	124	272	148	−. 4
300	. 75	43. 75	123	273	150	−. 4
200	. 50	43. 50	122	274	152	−4
100	. 25	43. 25	121	275	154	−4
0	. 00	43. 00 pi	120	276	156	−4

Example 89 is a typical example of computing the date constants directly from the local records by the standard rate of 1 day to 100 feet, in which the average of the spring date records for the B base altitude 700 feet is year date 127 and for autumn 269. Thus for the spring date constants for the altitudes above the base, 1 day is added to the record and below it 1 day is subtracted, for each 100 feet; while for the autumn date constants 1 day is subtracted from the record above, and 1 day is added below, the base altitude. The period constants in days are simply the differences between the spring and autumn dates; *pa* gives the position altitudes above the *pi* position isophane 43 at intervals of 100 feet and are extended to 1,400 feet (or 470 feet above the summit of Butcher Hill) to provide for extreme variations of the records from their equivalent constants; *le* gives the latitude equivalent in degrees to the altitude in feet, which plus the *pi* 43 gives the *ei* equivalent isophane to the altitude. Zonal constant gives the zones and zonal section constants as determined by the *ei* referred to a standard table of constants.

Thus, under the coordination of time and distance, the date and period constants represent the unit constant requirements of bioclimatic law and apply to either the *pa* directly or to the *ei* as in example 90. It will be noted that in example 89 the constants are computed for the position altitudes directly from the base records to show how local constants may be computed for any subject for the local altitudes.

SUMMARIZED RESULTS

These summarized results are shown in example 90.

EXAMPLE 90.—*Summarized results of studies of Kanawha Farms topographic types based on phenological records*

SECTION A, VARIATIONS AND TOPOGRAPHIC EFFECT TYPES

Area no.	Alt.	100-foot units	Spring				Autumn				Period				
			pc	*pr*	*pv*	*tet*	*pc*	*pr*	*pv*	*tet*	*pc*	*pr*	*pv*÷2=	*pv*	*tet*
Hill:															
9	935	900	129	124	−5	*wt*	267	272	+5	*wt*	138	148	+10	+5	*wt*
	850	800	128	126	−2	*w*	268	270	+2	*w*	140	144	+4	+2	*w*
8	800		128	126	−2	*w*	268	270	+2	*w*	140	144	+4	+2	*w*
7	750	B 700	127	127	0	*n*	269	269	0	*n*	142	142	0	0	*n*
6	700		127	128	+1	*n*	269	268	−1	*n*	142	140	−2	−1	*n*
Valley:															
5	675		126	129	+3	*c*	270	267	−3	*c*	144	138	−6	−3	*c*
4	655		126	129	+3	*c*	270	267	−3	*c*	144	138	−6	−3	*c*
	650	600	126	129	+3	*c*	270	267	−3	*c*	144	138	−6	−3	*c*
3	640		126	129	+3	*c*	270	267	−3	*c*	144	138	−6	−3	*c*
1	600		126	130	+4	*c*	270	266	−4	*c*	144	136	−8	−4	*c*
Ravine:															
2	630		126	134	+8	*ct*	270	262	−8	*ct*	144	128	−16	−8	*ct*

SECTION B, DIFFERENCE IN RECORD AND REQUIREMENT CONSTANT DATES BETWEEN HIGH AND LOW AREAS

Area no.	Alt.	Spring				Autumn			
		pc diff.	*pr*	*pr diff.*	*tet*	*pc diff.*	*pr*	*pr diff.*	*tet*
Hill:									
9	900	+3	124	0	*wt*	−3	272	0	*wt*
8	800	+2	126	+2	*n*	−2	270	−2	*n*
6–7	700	+1	127	+3	*c*	−1	269	−3	*c*
Valley:									
4–5	650	0	129	+5	*c*	0	267	−5	*c*
1 and 3	600	0	130	+6	*c*	0	266	−6	*c*
Ravine:									
2	630	0	134	+10	*ct*	0	262	−10	*ct*

SECTION C, ZONAL CONSTANTS AND RECORD TYPES

Area no.	Positions				Indices		*ZC*	Types	
	pa	*pi*	*le*	*ei*	*lvx*	*ri*		*zt*	*tet*
Hill:									
9	900	43. 00	+2. 25	45. 25	−1. 25	44. 00	. 4	−. 4	*wt*
8	800	43. 00	+2. 00	45. 00	−0. 50	44. 50	. 4	. 4	*w*
6–7	700	43. 00	+1. 75	44. 75	0	44. 75	. 4	. 4	*n*
Valley:									
4–5	600	43. 00	+1. 50	44. 50	+. 75	45. 25	. 4	. 4	*c*
1 and 3	600	43. 00	+1. 50	44. 50	+1. 00	45. 50	. 4	. 4	*c*
Ravine:									
2	630	43. 00	+1. 50	44. 50	+2. 00	46. 50	. 4	+. 4	*ct*
Sea level	0	43. 00	0. 00	43. 00	-------	43. 00	−4+5	------	----

Section A gives the area numbers of example 88; *alt.*, the altitude of the observation positions; *100-foot units* the levels at 100-foot intervals; *pc* the position year-date and period constants; *pr* the position records for spring, autumn, and period; *pv* the position variations in days of *pr* from *pc; tet* the topographic effect types; and *pv*÷2 equals *pv*, the position variation for the period in days between spring and autumn. It will be noted that the records for the areas vary from the earliest spring date 124 (May 4) in area 9 to the latest date 134 (May 14) in area 2, while the records for autumn events vary from the latest date 272 (Sept. 29) in area 9 to the earliest date 262 (Sept. 19) in area 2, and that the period record shows that the longest period between the spring and autumn dates is 148 days in area 9 and the shortest 128 days in area 2. Under *tet* for spring, autumn, and period it will be noted that the *wt* warmest type comes in area 9, the *ct* coldest type in area 2, the *c* cold in areas 1, 3, 4, and 5, and the *w* warm in area 8, while the *n* normal comes in the midslope areas 6 and 7.

In section B the differences between the record and requirement constant dates are shown for the given area numbers and altitudes by rates in days per 100 feet or less; *pc diff.* gives the unit constant rate or difference of 1 day to 100 feet above the 600-foot base level (as +1 day later in spring for 700 feet, +2 days for 800 feet, etc., and the reverse for autumn dates),

while by the *pr* it is shown that the rate, as modified by the topographic influences, is inverted, e. g., in *pr diff.* for spring and autumn the rates increase with lower instead of with higher altitudes. Thus the spring record date from 124 at 900 feet to 134 at 630 feet is plus 2 days for the first 100 feet, 3 days for 200 feet, 6 days for 300 feet, and 10 days for 270 feet, below the 900-foot level, with the reverse (minus) for autumn. Thus the average rate between 900 and 600 feet is 2 days to 100 feet, and between 900 and 630 feet it is 3 days per 100 feet.

In section C it is shown how the zonal types are determined for the local area coming between 600 and 900 feet, in which *pa* is divided by 400 (feet to 1°) to finds its *le*, which is added to *pi* to find the *ei*, and this in the isophane-zonal scale of a table of constants gives the *ZC;* then the *pv* position variation in days in section A is divided by 4 (days to 1°) to find the *lvx*, which plus or minus the *ei* gives the *ri*, which referred to the isophane-zonal column of any table of constants gives the zonal type. While the zonal constant for all areas is middle 4 of major II, the modified zonal types are lower middle 4 for area 9 and upper middle 4 for area 2.

The significant features of section A are in indicating (1) the location of the warmest, warm, cold, and coldest topographic effect types, and the relative length of seasonal periods in the areas above and below the base level at 700 feet, with the warmest type at the summits, the normal type on the upper middle slopes, the cold in the lowland valley, and the coldest type in the wooded ravines; (2) that the orchards and types of agriculture liable to be injured by late frosts in spring or early frosts in autumn should be located from the middle slopes to the high summits of the hills, as is strikingly demonstrated by (*a*) a successful orchard at about the 800-foot level on Butcher Hill, by (*b*) the frequent failures of orchards in the general floor of the valley, and (*c*) by the fact that in area 9 varieties of shrubs as *Spiraea vanhouttei*, *Diervilla*, and *Deutzia* are frequently winter killed in the valley but are uninjured on the hill; and (3) that on the average the spring events in the upper slope and summit areas are from −2 to −5 days earlier than the constants, while in the low ravine (area 2) the events are +8 days later than the constants and 4 days later than on the general valley floor.

In section B is shown the radical difference between the unit constant and record rates per 100 feet of altitude; the requirements of the law are completely reversed under the controlling topographic influences.

In section C the outstanding interest is in the zonal constants and inverted record zonal types; the highest and coldest section of minor zone 4 comes in area 2, and the lowest and warmest section comes in area 9.

The results of this study are in complete agreement with those of the North Carolina local areas in showing how the relative intensity of the influence of topographic factors within a local area causes an inversion of dates of spring and autumn phenological events from the requirements of bioclimatic law; how the relative effects may be interpreted by the application of bioclimatic principles; how the difference in the effects within a distance of less than 2 miles may be equivalent to a normal effect within a distance of about 3° of latitude or about 200 miles (e. g., between area 9 and area 2), or the difference may be equivalent to 1° of latitude within a few rods or feet (e. g., between the banks of the ravine of area 2 and the flat of area 1 immediately adjacent to it); and how the ravines of a valley may represent the coldest types, the lower and middle slopes of the hill a normal type, and the upper slopes, low middle, and high summits the warm and warmest types, as best adapted to fruit culture.[31]

TEMPERATURE STUDIES

In the seasons of 1916 and 1917 daily temperature records were kept during part of the spring, summer, and autumn at four stations in the valley, as follows:

Station 1, near the dwelling, to represent the average level of the valley floor in terrace 3, elevation 657 feet; station 2, near Gillispie cabin, to represent terrace 2, elevation 640 feet, horizontal distance 600 feet from station 1; station 3, near swimming pool in Cedar Brook ravine, to represent a broad ravine in terrace 2, elevation 630 feet, horizontal distance 100 feet from station 2; station 4, in Gillispie Brook ravine, to represent a low narrow enclosed ravine in terrace 2, elevation about 620 feet, horizontal distance about 1,050 feet from station 3 and about 1,750 feet from station 1.

General Results

These observations represent broken and irregular periods during the seasons of each year and, therefore, can be considered only as general evidence of the difference in the temperatures at the different stations, but these records show that, in general, as compared with station 1, (*a*) the mean maximum was higher at stations 2, 3, and 4, increasing to the highest at station 4 (station 2 +0.47, station 3 +0.93, and station 4 +1.65); (*b*) the mean minimum was lower at stations 2, 3, and 4, increasing to the lowest at 4 (station 2 −0.68, station 3 −1.34, and station 4 −1.82); (*c*) the range between the mean maximum and mean minimum was (+) greater at stations 2, 3, and 4, increasing to the greatest at station 4 (station 2 +1.02, station 3 +2.50 and station 4 +2.85); (*d*) the mean of the maximum and minimum was slightly greater at station 2 and lower at stations 3 and 4 (station 2 +0.11, station 3 −0.27, and station 4 −0.33); and (*e*) the highest recorded maximum and lowest minimum was at station 4.

Significance of Results

These results, indefinite as they are because of the limited number of seasons and brief periods in each, nevertheless (in agreement with the phenological records in example 90) show that within a very limited area and distance on a farm there may be a marked difference in the minimum temperature between the higher land represented by station 1 and the lower land represented by stations 2, 3, and 4. (See the profile, fig. 54.)

RELATION OF TEMPERATURE TO THE RETARDATION OF LIFE ACTIVITIES

Above a given effective temperature life activities are accelerated up to a critical maximum, above which they are retarded, and below a given temperature the activities are retarded to a critical minimum when activities cease or the organism is killed. It is known, also, that the zero of optimum or effective temperature varies with different species and even varieties of the same species. The published results of investigations indicate that the zero of effective temperature is in

[31] The results of similar studies just completed (1936) by Mr. Murray for the 10-year period (1926–35) correspond with the above results relative to the variability in periodical events and topographic influences within the local area of Kanawha Farms.

general between 40° and 50° F., with an optimum at about 50° to 60°. Thus we should expect that retardation would increase below 43° and that acceleration would increase above 43° to about 75°, when retardation would be more or less evident up to 80° or more.

Applying this principle to the phenological events at the four stations, since the lower stations show a higher mean maximum and also a higher sum-of-the-day temperatures, one might expect that the accelerating effects of the heat during the day would counterbalance the retarding effects of lower temperature at night, but when it is considered that the mean minimum and the sum of the daily minima show a decidedly lower temperature for the lower stations, it is evident that the mean of the minima is a better index to the relative intensity of the retarding influences than is the mean of the maxima to an accelerating influence. Furthermore, the minimum for the 24-hour period, for a period of days, is as a rule representative of more hours of low temperature and retarding influence than of high temperature and accelerating influence. In other words, the retarding influence prevails for more hours during the evening, night, and morning than does the accelerating influence between sunrise and sunset.

The results of a study of this problem, when compared with recorded phenological events at and near the four record stations, indicate quite clearly that temperature alone is not as reliable an index as has been supposed to the relative effects of topographic factors on the seasonal development of vegetation.

It is true, however, that the annual temperature is a reliable index to the minor zone, and the *w* and *c* temperatures are reliable indices to the warm and cold types, but, as related to the more specific interpretations for any place within a local area, there is no comparison in economy and practicability between the phenological and thermal bases of interpretation. While temperature is a reliable index to the relative cold or warm conditions of the air, it does not reflect the relation of the topographic influences to other elements of the climate and weather in the same way or as accurately as do *the seasonal events of plants*, which *respond to all of the local actors of acceleration and retardation.*

ECONOMIC SIGNIFICANCE OF RESULTS

The special economic significance of the studies of the local areas of North Carolina and Kanawha Farms is in showing that cultivated plants and types of farming are not only best adapted to certain minor zones or ranges of zones, but to special topographic, climatic, season, weather, soil, and other types.

Thus, while the apple and peach are adapted to a wide range of minor zones, as from minor zones 2 to 6 of major II, and, while the trees will grow almost anywhere within this range if the soil and weather conditions are favorable, they will not produce profitable crops of fruit in their northern and southern range or in the lowland where late spring frosts frequently kill the flowers or young fruit. There are many other fruits, crop plants, shrubs, and trees that are injured by late spring frosts, while others are damaged by early autumn frosts or winter freezing.

It is a well-known principle that fruit trees on highland slopes and summits of a hilly country are less liable to suffer from late frosts in spring, early frosts in autumn, or the severe cold of winter, than on the lowland slopes and in enclosed valleys. Meteorologists have shown that this is due mainly to the inversion of temperature, in which the cold air flows down into the lowland and the warm air rises to the highland during clear calm nights. Meteorologists have also outlined principles and methods for the location of frost and frostless belts and areas, which, in addition to the bioclimatic principles and methods outlined and illustrated in this section, should enable the scientific advisor or practical fruit grower to locate the favorable topographic types for any given local area or farm.

The results of the phenological and thermal observations here described lead to the following definite conclusions relative to the law of topographic influence and its corresponding effects on plants and animals: (1) From highland summits and slopes to lowland valleys, ravines, and depressions within a valley floor there is in general a more or less progressive lowering of the mean minimum and annual mean temperatures, with corresponding retardation of spring, and acceleration of autumn, events, and a shorter growing season; (2) under equal conditions of air drainage from the higher to the lower levels, this trend of lower temperature is greatest during clear still nights and least during cloudy or windy nights, and that the relative effects (as manifested in retardation of spring, and acceleration of autumn, events) is under the average influence of topographic factors; (3) late killing frosts in spring and early killing frosts in autumn

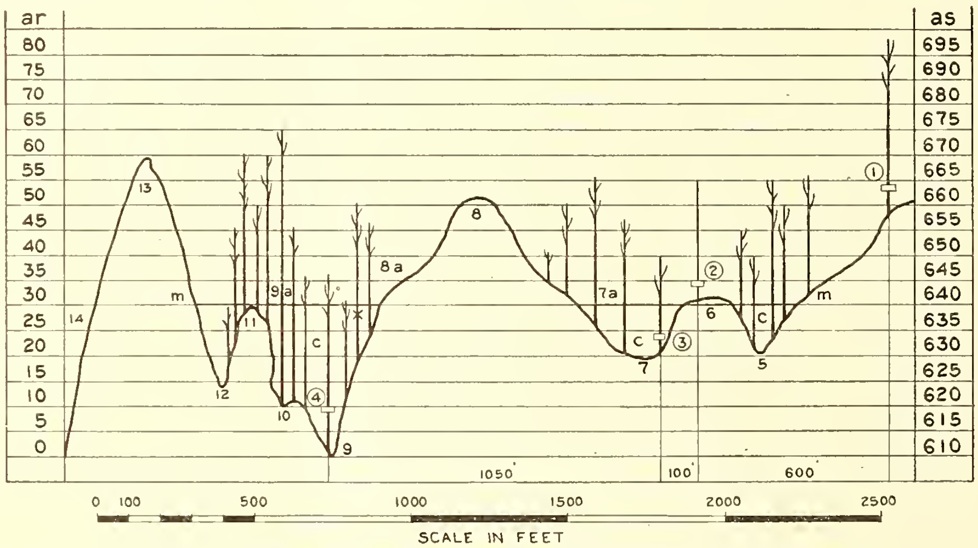


FIGURE 54.—Topographic profile with location of thermal stations at Kanawha Farms.

are controlled by the same factors as those which cause the inversion of temperature; (4) between the summits and slopes of the highland and the colder levels of the lowland there is usually an intermediate level which represents a norm or average between the colder and warmer types; (5) the intensity of the local topographic influence in causing the warmest type is greatest at the open summits and on the middle-to-upper slopes of the highland up to varying limits, while that causing the coldest type is greatest in enclosed valleys, depressions, and ravines in low, wet, or boggy places within an open or enclosed valley, and on the lower slopes of ravines and enclosed coves of the highland; (6) this principle of the law of topographic influence applies alike (but in varying degrees) to major, minor, and subminor topographic types in causing warm, normal, and cold effect types of areas of all sizes down to places a few feet square, wherever there is a contrast between the higher and lower levels of the surface of the land; and (7) preliminary interpretations of the warm, normal, and cold topographic types of the major and minor regions of a continent or country, and of local areas and specific places, wherever the geographic position and range in latitude, longitude, and altitude above the sea is known, can be made by the application of bioclimatic principles of the *variable* and *constant* in time, temperature, and distance.

Thus *preliminary* interpretations can be made from the average of the annual mean temperature and the average of the means of the warmest or of the coldest months, as recorded for a number of years at regular meteorological stations, which are generally representative of the *local region; better* interpretations can be made with supplementary information on the topographic and biologic features of the given *local region or area; very accurate and reliable* interpretations can be made for *local areas* from averages of authentic phenological records; and *specific* interpretations can be made for *any place*, when the preliminary evidence is supplemented by local observations.

RELATION OF BIOCLIMATICS TO THE OTHER SCIENCES

Although bioclimatics cannot be assigned specifically to any one of the natural sciences, it is related to all. As the term implies, it is more nearly related to biology and climatology, but its laws of cause are based on the principles of astronomy, physics, physiography, and geology, and its laws of effect on the principles of geographic distribution and zonation of life, climate, weather, seasons, and the adaptations of plants and animals to their environments.

Bioclimatics was dependent for its conception upon phenology; and for its development it was also dependent upon climatology, meteorology, geography, biology, and other sources of recorded data. Thus gradually were developed (*a*) the principle of the *constant* and *variable* and the variation of the record variable from its constant as the *index* to modifications in the latitude and altitude range and limit constants of the seasonal, climatic, and bioclimatic zones and zonal types; (*b*) the principle of the zone and zonal type as an index to the interpretation of general and specific adaptational requirements in the geographic distribution of types of native and introduced plants and animals, types of agriculture, etc.; and (*c*) the principle of interpretation of zones and types for local areas and specific places as modified by local topographic types.

PHENOLOGY

Phenology is a minor branch of science of somewhat doubtful position. It is a branch of biology but it is also related to climatology and meteorology in that its dates and periods of seasonal events are related to the climate and the weather. It is also related to geography in that its dates and periods indicate the geographic range and distribution of types of seasons, climates, and bioclimatic zones. Thus phenology is destined to be the most important science in the future development of bioclimatics.

ECOLOGY

Ecology is plainly a branch of biology coming between botany and zoology, because it deals specifically with the association of plants and animals under the influence and control of environmental factors. The place and mission of ecology is similar to that of meteorology, bioclimatics, and phenology in that its greatest service is in making its principles, systems, and methods available to specialists in other branches of biological research and economic practice.

A special service to be rendered by ecology to bioclimatics, phenology, and specialized biology, and through them to agriculture and other human interests, is in interpreting the local ecological type of the bioclimatic zone, which may be used as a guide to the selection of the types of plants and animals that are more likely to succeed in any given environment.

Thus it is plain that climatology, meteorology, bioclimatics, phenology, and ecology, each with its distinctive principles and field of research, represent an interrelated and interdependent group of borderland sciences, which can be of service in making available to specialists in other sciences certain laws, principles, systems, and methods essential to the solving of certain general and specific problems of agriculture.

CLIMATOLOGY

The service of bioclimatic principles to research problems of climate and weather of the world include the major subjects of (*a*) past or paleo-climates, and (*b*) present or post-glacial climates.

PALEO-CLIMATES

Bioclimatics can render a service in the study and interpretation of the climate of geological periods, as controlled by the great changes that have occurred in geological time, including (*a*) studies of the present relations of astronomical, astroterrestrial, and terrestrial laws of control and modification of the seasons; (*b*) studies of the laws and principles of variation and distribution of the world and continental climates, as controlled by the present distribution of the continents and oceans and the elevation of the land above the sea; (*c*) studies of effects, as manifested by the variation in climates of the same latitude across the northern and southern continents in relation to the requirements of astronomic and bioclimatic laws; (*d*) utilizing the evidence thus supplied as a guide to the interpretation of the major and minor changes of the past, as controlled by the distribution of land and water; (*e*) comparing the results of various combinations of possible changes in the relations between continents and oceans with the geological evidence and with the paleontological evidence; and (*f*) drawing conclusions as to the

probable changes that have occurred within the major astronomic zones since life arose.

POST-GLACIAL CLIMATES

In the consideration of the history of climates of the world since the close of the last great period of glaciation in North America and northern Europe, the first evidence as to the character of the climate immediately preceding and following the retreat of the continental glaciers is found in recent paleontological materials. It is only within the past few centuries that sufficient records have been made of climatic elements on which to base comprehensive studies for an interpretation of the climates of the continents from a bioclimatic point of view.

The average temperature for a period of years, as recorded at representative meteorological stations and represented by the annual mean, is the reliable index to the thermal and bioclimatic zone that is represented by the position of any given station; the mean of the warmest month is an index to the warm type; the mean of the coldest month is an index to the cold type of the *a* zone; and finally the combination of the three, or rather the relation of the variations of the warm and cold means to that of the *annual* mean, is an index to the major and minor *climatic type* represented by the record position.

These three basic thermal index elements of climate are applied and the results interpreted under the principle of the constant and variable. With the *a*, *w*, and *c* variation indices determined for all of the record stations within a region or continent, the range and limits of the warm and cold zonal types, the *a* zone, and the climatic type as represented by the combination, can be interpreted and given in lists of specific positions or shown on outline maps.

ECONOMIC BIOLOGY

With the laws, principles, systems, and methods as outlined in these pages, together with the tables, charts, maps, and test examples, all the specialist has to do in any branch of biological research is: (1) To study the essential principles of bioclimatics and endeavor to understand how they may be applied to his special subject of research; (2) to select such of the principles as are more directly related to his subject; and (3) through test examples by recorded facts (as related to physiographic, seasonal, climatic, biologic, and other subjects) to apply them to his unsolved problems.

It is, therefore, in the application of bioclimatic principles to research in the many branches of economic biology, as related especially to agriculture, that some of the best service may be rendered to science and economic practice.

AGRICULTURE

From the studies and examples outlined or developed in the previous pages—studies based on records from various parts of the United States and of the world and on original researches in the science of bioclimatics—it is clearly apparent that the greatest need is for the application of bioclimatic principles to the economic adjustment of agricultural practice to meet the local and regional requirements, because (1) as controlled by the average season, climate, weather, soils, markets, etc., *there is in each region and local area, even on each farm, not only a best time for each seasonal practice, but a best type of each product and a best type of agriculture to meet the peculiar regional and local requirements for the best returns;* and (2) by the application of bioclimatic principles a large part of the essential preliminary information on which to base plans for such economic adjustments can be interpreted in advance from available records of a few essential bioclimatic facts for one or more representative positions within a given region.

To meet this need a comprehensive study should be made of present conditions as they have resulted from psychological movements and the "rugged individualism" of the agricultural population, through the laws of trial and error, supply and demand, and available transportation and markets.

The guiding principles in such a study should be (1) the present adjustments of agriculture to the geographic and physiographic features of the major and minor climatic regions of the entire country; (2) the geographic range and limits of the major types of agriculture or farming, such as general, specialized, individual, cooperative, extensive mechanized, etc.; (3) the geography of the major types of agricultural products, such as wheat and corn among the cereals, cotton, tobacco, citrus and other fruits, vegetables, livestock, etc.; and (4) the relation of the major and minor types of production and products to (*a*) the major and minor regions of the country, (*b*) the major types of climate, weather, and seasons, (*c*) the major and minor types of soils, (*d*) the major types of natural vegetation, and (*e*) the major transportation and market facilities.

With this preliminary information, much of which is now available in the literature, bioclimatics can render a very great service in the prompt development of further information on (1) the general range and limits of major coastal, mountain, interior, continental, and transition types of climate; (2) the general range and limits of the major and minor thermal, bioclimatic, and season zones; and (3) the physiographic, thermal, weather, seasonal, vegetation, and other bioclimatic elements and types of the minor zones. All of this information should be shown on a system of national, regional, state, or county maps, and further illustrated by charts, tables, and examples to serve as a basis for a systematic study and interpretation of the laws of adaptation and natural adjustment of native plants and animals as a guide to the required artificial adjustment.

With these two sources of information available, the next step should be a comprehensive and specialized study of the present crop adjustments, with special reference to those which have succeeded or failed, in other words, a study of many examples of success and failure within given major and minor regions, with reference to the characteristic minor zones and zonal types. The results of these studies will then serve as a basis for a general bioclimatic survey to determine the zones and zonal types where successes and failures of given types of production and products may be expected.

Throughout this contribution it has been fully explained and verified by concrete examples that the special service to be rendered through an understanding and general application of bioclimatic principles and methods of procedure is to contribute to the efficiency of securing essential basic information on the places, local areas, and regions in this and other countries where given types of farming and types of products have succeeded best and where they have failed, and then to aid in finding by the same process of analyses the places in this country where the same favorable or unfavorable conditions prevail.

PART 3. APPENDIX

GENERAL EXPLANATION

Brief explanations and references to test examples and figures are given under each table, schedule, or illustration. There are, however, a few fundamental principles and methods of procedure which apply alike to all tables of constants, as follows:

1. *The time, thermal, or distance tables of constants*, except where otherwise specified, are computed for the isophane requirements of bioclimatic law and apply alike within the given range of isophanes to the continental areas of the northern and southern hemispheres.

2. All of the tables computed for ranges in isophane from the intercontinental base apply alike to the parallels of latitude requirements of astronomic law.

3. The thermal, time, or distance *isophane* or *latitude* constant for any position of known geographic coordinants (latitude, isophane, longitude, and altitude) is determined from its corresponding table by the equivalent *isophane* or *equivalent latitude* at sea level to the altitude of the position above sea level.

4. For any position with available thermal, time, or distance records the given record for a given subject referred to its nearest corresponding constant in a table will give in the scale of isophanes the *record isophane* and the *record latitude*, and in the scale of zonal constants the *zone* or *zonal type* represented by the *record position.*

5. Variation or departure of the position record from its requirement constant of bioclimatic law, or from its requirement constant of astronomic law, is determined in *equivalent degrees of latitude* by the difference between the *equivalent isophane* and *record isophane* for the isophane variation, or between the *equivalent latitude* and *record latitude* for the latitude variation.

6. The isophane or latitude variation (*iv*, *lv*, and *lvx*) determined for a record position serves as (*a*) *latitude variation index* to, or measure of, the relative intensity of the modifying influences, and (*b*) an index to the variation for nonrecord positions coming within the range of the same modifying influences as are represented by the record position or by the average of the records or variations of a number of positions within a given general area or local region.

7. Because of the coordinate elements of the system of thermal, time, and distance tables of requirement constants, the variations, zones, zonal types, and any corresponding bioclimatic element or combination of elements, as determined for any given record or nonrecord position, are directly comparable with the same elements which are determined in the same way for any other record or nonrecord position within the same region or any other region.

SCHEDULES

SCHEDULE 1

SCHEDULE 1.—*Lowest temperature types*

Range	Mean	Range	Mean
−90 to −60	−75	0 to +5	+2
−60 to −40	−50	+5 to +10	+7
−40 to −30	−35	+10 to +15	+12
−30 to −20	−25	+15 to +20	+17
−20 to −15	−17	+20 to +30	+25
−15 to −10	−12	+30 to +40	+35
−10 to −5	−7	+40 to +50	+45
−5 to 0	−2		

EXPLANATION OF SCHEDULE 1

The lowest recorded temperature for a record position, designated by the symbol letter *g*, is so variable at different positions within the same local area or region that it does not conform to the requirements of bioclimatic or of any other law except that of topographic influence. Therefore, it is not practicable to represent this element by constants.

It is found, however, that a schedule of arbitrary constants can be utilized to distinguish low temperature types of the *a* zone, or of the *w* and *c* zonal types, and to serve as an index to the interpretation of the *lowest temperature type* represented by any position for which the lowest temperature record is available. Thus from it one may interpret the lowest temperature to be expected under varying topographic influences at nonrecord positions within the region represented by the record stations.

In the application of this schedule the record for a position is referred to the nearest range type to it in the schedule, or to the *mean type* coming nearest to it; the record in ° F. serves to indicate the lowest temperature type.

EXAMPLES OF APPLICATION

Part 1: Thermal record card A.
Part 2: Examples 53, 71, 73.

SCHEDULE 2

SCHEDULE 2.—*Monthly or daily thermal mean indices for the beginning of the seasons*

[Thermal indices in degrees Fahrenheit]

Latitude	Spring	Summer	Autumn	Winter
Above 60	35			35
60 to 57	40	55	55	40
57 to 51	43	60	60	41
51 to 27	45	*Interior* 64 or 66	64	43
57 to 27	40 or 43	*West coast* 53, 55, or 60	53, 55, or 60	43

EXPLANATION OF SCHEDULE 2

The purpose of this schedule is to provide standard indices by which the approximate average beginning dates of terrestrial spring, summer, autumn, and winter can be interpreted for any position with thermal records within season zone II.

Latitude gives ranges in sea-level latitude in which the given thermal indices apply regardless of altitude, because the record mean is for the position altitude. In other words, the given latitude ranges serve only as guides to the thermal index for each season to be selected for positions coming within the given ranges.

The development of this schedule represents a comprehensive study of the relations of the monthly or daily normal mean temperatures to the beginning of the seasons in the Intercontinental Base Area, as indicated by the average dates of phenological events there, and at places in Europe where phenological records have been kept for long periods of years. It is verified by many test examples for widely separated record positions under different modifying influences on the northern and southern continents, with allowance for the difference in months for the beginning and ending of the seasons.

The method of procedure for a given record position is to find the position latitude and note the range in which it comes in the schedule, and then utilize the given indices to refer to the record monthly means coming nearest to it, which gives the beginning date. For example, if a given index comes nearest to the mean for a given month it will indicate the 15th, but if the mean of the first month is much higher and that of the next month is much lower than the index, a date is selected coming between the 15th of one month and the 15th of the next month, depending on the relation of the index to the 15th of the 2 months, the 23d of the first month, and the 1st or the 7th of the next month. Thus by this method the corresponding date of a given month coming nearest the index for a given season is selected as the beginning date.

While this method necessarily involves some error, it has been found by many test examples and comparisons with the beginning dates of the phenological seasons that, as a rule, the interpreted dates come near enough on the average to meet the requirements for preliminary information on the beginning of the seasons at a given position, and also enable one to determine variations and zonal types for the northern hemisphere, by referring the interpreted record dates to their corresponding constants in table 9.

When the daily normal means are available for a position, the process is simplified by utilizing the date of the daily mean corresponding to the index mean. This may or may not be more accurate, but, since such published records are not available for a large majority of record positions, the monthly mean principle and method must be utilized for such positions.

For regions of marked modifying influences, like those of the western coasts and interior basins, it may be necessary for such positions to utilize a modified index, e. g., for western coast regions the lower index of 40° F. for spring; and 53°, 55°, or 60° for summer and autumn between latitudes 57 and 27; while transition regions like that of the base may require a slightly higher summer index of 66° for the same latitudes. In the interest of standardization and the attainment of comparable results, however, it is not advisable to apply the modified indices except in special areas or regions where it is plainly desirable to interpret a closer relation between the thermal and phenological seasons.

Example 91 shows the method of determining the dates of the beginning of thermal seasons.

In section A, the spring index for St. Paul Island comes nearest to the monthly mean temperature for June giving June 15, year date 166, as the beginning date. The means for July, August, and September are all below the indices for summer and autumn; that for winter comes between September 15 and October 15, or September 23. As there is no summer temperature, there is a warm spring-autumn period of 100 days between the beginning of spring and the beginning of winter. For Buffalo, Wyo., the spring index comes between April 15 and May 15, giving April 23 as the beginning date; the summer index comes half way between June 15 and July 15, giving July 1; the autumn date is August 23, and the winter date October 23. For Lafayette, Ind., the winter index comes between October 15 and November 15, but being nearer the latter, November 7 is selected as the beginning date. For Miami, Fla., all of the monthly means are above the season indices, indicating a continuous summer temperature.

In section B the variations of the record or interpreted year dates from the requirement constants of table 9 for the beginning of each season are determined by the difference between *el* and *rl* by the *pr* date coming nearest to a date constant. Thus by latitude, the difference between *el* and *rl* gives the *lv* variation in degrees of latitude, which multiplied by 4 days for each degree gives the equivalent *dv* variation. Under warm period the variations are from *rp*. By isophane, the same process gives the variations from the isophane requirements. A study of the variations from *el* and *ei* requirements shows that with the exception of those variations for spring, winter, and warm period for St. Paul Island, summer for Lafayette, and warm period for Miami, the variation for the beginning of each season and length of the warm period is less from the requirements of bioclimatic law than from that of astronomic law.

In section C the zonal types represented by the *pr* dates and periods through the *rl-ri* record latitude-isophane are determined by the zonal constants for the isophanes in table 9.

EXAMPLE 91.—*Method of determining the dates of the beginning of the thermal seasons by application of schedule 2, together with variations and zonal types as determined by reference to table 9*

SECTION A. TO DETERMINE BEGINNING DATES AND LENGTH OF THE WARM PERIOD

1. St. Paul Island, Alaska; *pl* 57.25, *plo* 170, *pa* 0, *pi* 43.00.
pl 57.25, indices, *Sp* 40, *Su* 55, *Au* 55, *Wi* 43.
Monthly means: June 40.7, July 45.3, August 46.1, September 44.1, October 38.6.

	Spring	Summer	Autumn	Winter	Warm period
Beginning dates.	June 15, 166			Sept. 23, 266	100 days.

2. Buffalo, Wyo.: *pl* 44.25, *plo* 106, *pa* 4600, *pi* 43.00.
pl 44.25, indices, *Sp* 45, *Su* 64, *Au* 64, *Wi* 43.
Monthly means: April 42.7, May 50.7, June 60.8, July 68.0, August 66.6, September 56.9, October 45.9, November 34.7.

	Spring	Summer	Autumn	Winter	Warm period
Beginning dates.	Apr. 23, 113	July 1, 182	Aug. 23, 235	Oct. 23, 296	183 days.

3. Lafayette, Ind.: *pl* 40.25, *plo* 86, *pa* 600, *pi* 43.00.
pl 40.25, indices, *Sp* 45, *Su* 64, *Au* 64, *Wi* 43.
Monthly means: March 38.6, April 50.5, May 61.7, June 70.9, July 74.9, August 72.8, September 66.2, October 53.9, November 40.4.

	Spring	Summer	Autumn	Winter	Warm period
Beginning dates.	Apr. 1, 91	May 23, 143	Sept. 23, 266	Nov. 7, 311	220 days.

4. Miami, Fla.: *pl* 25.75, *plo* 80, *pa* 100, *pi* 29.75.
pl 25.75, indices, *Sp* 45, *Su* 64, *Au* 64, *Wi* 43.
Montbly means: All above 67.
Beginning dates: Jan. 1 to Jan. 1; perpetual summer; warm period 365 days.

SECTION B. TO DETERMINE VARIATIONS FROM EQUIVALENT LATITUDE AND EQUIVALENT ISOPHANE

pno	*el*	Spring				Summer				Autumn				Winter				Warm period			
		pr	*rl*	*lv*	*dv*	*pr*	*rl*	*lv*	*dv*	*pr*	*rl*	*lv*	*dv*	*pr*	*rl*	*lv*	*dv*	*rp*	*rl*	*lv*	*dv*
1	57.25	166	64.50	+7.25	+29									266	56.75	−0.50	−2	100	61.00	+3.75	+15
2	55.75	113	51.50	−4.25	−17	182	51.75	−4.00	−16	235	52.25	−3.50	−14	296	49.00	−6.75	−27	183	50.50	−5.25	−21
3	41.75	91	46.25	+4.50	+18	143	42.50	+.75	+3	266	44.50	+2.75	+11	311	45.25	+3.50	+14	220	45.75	+4.00	+16
4	26.00																	365	27.00	+1.00	+4
pno	*ei*	*pr*	*ri*	*iv*	*dv*	*pr*	*ri*	*iv*	*dv*	*pr*	*ri*	*iv*	*dv*	*pr*	*ri*	*iv*	*dv*	*rp*	*ri*	*iv*	*dv*
1	43.00	166	64.50	+21.50	+86									266	56.75	+13.75	+55	100	61.00	+18.00	+72
2	54.50	113	51.50	−3.00	−12	182	51.75	−2.75	−11	235	52.25	−2.25	−9	296	49.00	−5.50	−22	183	50.50	−4.00	−16
3	44.50	91	46.25	+1.75	+7	143	42.50	−2.00	−8	266	44.50	.00	0	311	45.25	+0.75	+3	220	45.75	+1.25	+5
4	30.00																	365	27.00	−3.00	−12

SECTION C. TO DETERMINE ZONAL TYPES

pno	Spring			Summer			Autumn			Winter			Warm period		
	pr	*rl-ri*	*zt*	*pr*	*rl-ri*	*zt*	*pr*	*rl-ri*	*zt*	*pr*	*rl-ri*	*zt*	*rp*	*rl-ri*	*zt*
1	166	64.50	I .4							266	56.75	II +2	100	61.00	I −.4
2	113	51.50	II −2	182	51.75	II −2	235	52.25	II −.2	296	49.00	II .3	183	50.50	II +3
3	91	46.25	II .4	143	42.50	II +5	266	44.50	II .4	311	45.25	II .4	220	45.75	II .4
4													365	27.00	III .1

EXAMPLES OF APPLICATION

Part 1: Examples 6 and 7; figure 15.
Part 2: Examples 54, 71, 72, 73, 75, 76, 77, 78, 79, 80, 81, 82, 84, 85, 86, 87; figure 49.

SCHEDULE 3

Schedule 3.—*Relative humidity types in percentage and precipitation types in inches*

SECTION A

Relative humidity in percentage				Precipitation in inches			
Type Sym.	Condition	Annual Range	Annual Mean	Type Sym.	Condition	Annual Range	Annual Mean
D	Dry	Under 25	12	A	Arid	Under 4	2
D1	do	25 to 35	30	A1	do	4 to 10	7
D2	do	35 to 45	40	SA	Subarid	10 to 15	13
D3	do	45 to 55	50	SH1	Subhumid	15 to 20	17
				SH2	do	20 to 30	25
M	Moist	55 to 65	60	H1	Humid	30 to 40	35
M1	do	65 to 75	70	H2	do	40 to 50	45
M2	do	75 to 85	80	H3	do	50 to 60	55
M3	do	85 to 95	90	H4	do	60 to 70	65
				H5	do	70 to 80	75
				H6	do	80 to 90	85
				H7	do	90 to 100	95
				H8	do	Over 100	100

SECTION B

Mg	Month of greatest precipitation											
Abbr	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
No	1	2	3	4	5	6	7	8	9	10	11	12

Ml	Month of least precipitation											
Abbr	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
No	1	2	3	4	5	6	7	8	9	10	11	12

EXPLANATION OF SCHEDULE 3

The object of this schedule is to give standard indices to characterize humidity types in percentages of relative humidity and to characterize precipitation types in inches. The types are designated by capital letters and by combinations of capital letters and arabic numbers, as related especially to gradations (*a*) in dry and moist types of humidity and (*b*) in arid and humid types of precipitation.

In section A, under relative humidity, are given gradations in *range* of percentage and the approximate *mean* percentage; and under precipitation, gradation in inches and the *mean* for the year.

In section B, under month of greatest and least precipitation are given the abbreviations for the names of the months and their designations by numbers, either of which will serve as type symbols in connection with the amount in inches.

In the application of section A the record annual range or mean for a position, area, or region in percentage of relative humidity or inches of annual precipitation is referred to the corresponding *range* or *mean* of the schedule to find the relative *humidity* or *precipitation type* coming nearest the record, which type may be designated by the required symbol.

In the application of section B the *record* average of the month or months of greatest and least precipitation at a given position are determined, and the month type is designated by the month symbol or month number.

EXAMPLES OF APPLICATION

Part 1: Example 8.
Part 2: Examples 53, 59, 71, 73.

SCHEDULE 4

Schedule 4.—*Month and year dates for a normal year by the 12-month calendar*

1	2	3	4	5	6	7	8	9	10	11	12
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	32	60	91	121	152	182	213	244	274	305	335
2	33	61	92	122	153	183	214	245	275	306	336
3	34	62	93	123	154	184	215	246	276	307	337
4	35	63	94	124	155	185	216	247	277	308	338
5	36	64	95	125	156	186	217	248	278	309	339
6	37	65	96	126	157	187	218	249	279	310	340
7	38	66	97	127	158	188	219	250	280	311	341
8	39	67	98	128	159	189	220	251	281	312	342
9	40	68	99	129	160	190	221	252	282	313	343
10	41	69	100	130	161	191	222	253	283	314	344
11	42	70	101	131	162	192	223	254	284	315	345
12	43	71	102	132	163	193	224	255	285	316	346
13	44	72	103	133	164	194	225	256	286	317	347
14	45	73	104	134	165	195	226	257	287	318	348
15	46	74	105	135	166	196	227	258	288	319	349
16	47	75	106	136	167	197	228	259	289	320	350
17	48	76	107	137	168	198	229	260	290	321	351
18	49	77	108	138	169	199	230	261	291	322	352
19	50	78	109	139	170	200	231	262	292	323	353
20	51	79	110	140	171	201	232	263	293	324	354
21	52	80	111	141	172	202	233	264	294	325	355
22	53	81	112	142	173	203	234	265	295	326	356
23	54	82	113	143	174	204	235	266	296	327	357
24	55	83	114	144	175	205	236	267	297	328	358
25	56	84	115	145	176	206	237	268	298	329	359
26	57	85	116	146	177	207	238	269	299	330	360
27	58	86	117	147	178	208	239	270	300	331	361
28	59	87	118	148	179	209	240	271	301	332	362
29	------	88	119	149	180	210	241	272	302	333	363
30	------	89	120	150	181	211	242	273	303	334	364
31	------	90	------	151	------	212	243	------	304	------	365

In leap year add 1 day from Feb., 59 to 365, inclusive.

EXPLANATION OF SCHEDULE 4

In this 12-month calendar January gives the month dates which apply from the first to the last dates of all months, so that the corresponding year-date for any month is found on the line of its month date in the January column, and the month date for any year-date is found by the reverse process. The principal reasons for the adoption of the year-date as a standard expression or measure of time are (1) that it applies to all calendars, ancient and modern, beginning with Jan. 1, and will apply to any of the proposed reforms, including either the 12- or 13-month year as may be finally adopted for the normal 365 days with 1 day added for leap year; (2) the year-date is more convenient and practical for computing time in units of 24 hours, designated in bioclimatics as the *observation day or date*, and for determining the period in observation days between any one year-date and any other date in consecutive order during the year, for comparison with the requirement date constant for the same event at the same observation or record position.

In bioclimatics *consecutive* rather than *inclusive* days are used so that periods may be computed simply by subtracting the first date from the last.

In applied bioclimatics the *fraction of a day is not recognized except in averages*, and even then it is often best to refer fractions of a half or more of one day to the next full day, or those less than a half to the same day, thus avoiding the complication of fractions. There are, of course, some exceptions to this rule to meet certain specific requirements.

SCHEDULE 5

SCHEDULE 5.—*Sums of 12-hour units and percentage of daytime*

Zones		North lat.	1 spring		2 summer		3 autumn		4 winter	
Ma	*Mi*		*dt*	Percent	*dt*	Percent	*dt*	Percent	*dt*	Percent
I	−3	66.46	143	76.8	144	77.4	52	28.8	51	28.6
	−4	60.00	125	67.2	126	67.7	64	35.5	63	35.3
II	−1	57.00	121	65.0	121	65.0	68	37.7	66	37.0
	−2	51.00	115	61.8	115	61.8	72	40.0	71	39.8
	−3	48.00	113	60.7	113	60.7	74	41.1	73	41.0
	−4	43.00	110	59.1	110	59.1	77	42.7	76	42.6
	−5	40.00	109	58.6	109	58.6	78	43.3	77	43.2
	−6	34.00	105	56.4	105	56.4	81	45.0	80	44.9
	−7	30.00	103	55.3	103	55.3	82	45.5	81	45.5
III	.1	27.00	102	54.8	102	54.8	*Lat.* 83	46.1	82	46.0
	.4	3.00S	93	50.0	93	50.0	3N. 90	50.0	89	50.0
	.1	27.00	86	46.2	86	46.2	99	55.0	98	55.0
II	−7	30.00	85	45.6	85	45.6	100	55.5	99	55.6
	−6	34.00	83	44.6	83	44.6	102	56.6	101	56.7
	−5	40.00	81	43.5	81	43.5	104	57.7	103	57.8
	−4	43.00	79	42.4	79	42.4	106	58.8	105	58.9
	−3	48.00	76	40.8	76	40.8	109	60.5	108	60.6
	−2	51.00	74	39.7	74	39.7	111	61.6	110	61.7
	−1	57.00	69	37.0	69	37.0	117	65.0	116	65.1
I	−4	60.00	66	35.4	65	35.4	121	67.2	120	67.4
	−3	66.46	53	28.4	53	28.4	137	76.1	137	76.9
		South	1 autumn		2 winter		3 spring		4 summer	
Total	------	----------	186	------	186	------	180	------	178	------

	Hours		
	24	12	12
North			
1 spring, March equinox to June solstice	93	186	----
2 summer, June solstice to September equinox	93	186	372
3 autumn, September equinox to December solstice	90	180	----
4 winter, December solstice to March equinox	89	178	358

SCHEDULE 5.—*Sums of 12-hour units and percentage of daytime*—Continued

	Hours		
	24	12	12
South			
3 spring, September equinox to December solstice	90	180	----
4 summer, December solstice to March equinox	89	178	358
1 autumn, March equinox to June solstice	93	186	----
2 winter, June solstice to September equinox	93	186	372

EXPLANATION OF SCHEDULE 5

This schedule gives the scale of standard major and minor zonal constants of table 3 from minor −3 major I to minor .4 major III north and south, with corresponding latitudes and *dt* 12-hour units of daytime and *percent* percentage of day to the total units of daytime and nighttime for each of the four seasons, followed by a list of the astronomical seasons *north* and *south* and the sums of 24- and 12-hour units for each between the dates of the equinoxes and solstices, and the sum of 12-hour units for the spring and summer, the autumn and winter periods.

These daytime constants are used for the interpretation of the seasonal *daytime zonal type* of a given record or interpreted zone for any given isophane and latitude position at or above sea level. The *a* zone is determined in the usual way by the position record of the average annual mean referred to appendix table 3; and the daytime type by referring the position latitude to this schedule or to table 15.

The percentage of day is the determined sum for a given latitude divided by the total sum of 12-hour units of daytime and nighttime for the given period, e. g., 143 units divided by 186 units equals 76.8 percent of daytime for spring in latitude 66.46° N.

EXAMPLES OF APPLICATION

Part 2: Examples 54, 71, 75.

TABLES

TABLE 2.—*Modified thermal mean constants for application in the interpretation of the a, w, and c requirements for geographic positions*

Isop.	*a*	*w*	*c*	*Alt.*	*Isop.*	*a*	*w*	*c*	*Alt.*	*Isop.*	*a*	*w*	*c*	*Alt.*
90.00	−4.50	+32.50	−41.50	0	79.25	11.63	45.94	−22.69	4,300	68.50	27.38	59.00	−4.25	8,600
89.75	−4.13	32.81	−41.07	100	79.00	12.00	46.25	−22.25	4,400	68.25	27.69	59.25	−3.87	8,700
89.50	−3.75	33.13	−40.63	200	78.75	12.37	46.56	−21.82	4,500	68.00	28.00	59.50	−3.50	8,800
89.25	−3.37	33.44	−40.19	300	78.50	12.75	46.88	−21.38	4,600	67.75	28.31	59.75	−3.13	8,900
89.00	−3.00	33.75	−39.75	400	78.25	13.13	47.19	−20.94	4,700	67.50	28.63	60.00	−2.75	9,000
88.75	−2.63	34.06	−39.32	500	78.00	13.50	47.50	−20.50	4,800	67.25	28.94	60.25	−2.37	9,100
88.50	−2.25	34.38	−38.88	600	77.75	13.87	47.81	−20.07	4,900	67.00	29.25	60.50	−2.00	9,200
88.25	−1.87	34.69	−38.44	700	77.50	14.25	48.13	−19.63	5,000	66.75	29.56	60.75	−1.63	9,300
88.00	−1.50	35.00	−38.00	800	77.25	14.63	48.44	−19.19	5,100	66.50	29.88	61.00	−1.25	9,400
87.75	−1.13	35.31	−37.57	900	77.00	15.00	48.75	−18.75	5,200	66.25	30.19	61.25	−.87	9,500
87.50	−.75	35.63	−37.13	1,000	76.75	15.37	49.06	−18.32	5,300	66.00	30.50	61.50	−.50	9,600
87.25	−.37	35.94	−36.69	1,100	76.50	15.75	49.38	−17.88	5,400	65.75	30.81	61.75	−.13	9,700
87.00	−.00	36.25	−36.25	1,200	76.25	16.13	49.69	−17.44	5,500	65.50	31.13	62.00	+.25	9,800
86.75	+.37	36.56	−35.82	1,300	76.00	16.50	50.00	−17.00	5,600	65.25	31.44	62.25	.63	9,900
86.50	.75	36.88	−35.38	1,400	75.75	16.87	50.31	−16.57	5,700	65.00	31.75	62.50	1.00	10,000
86.25	1.13	37.19	−34.94	1,500	75.50	17.25	50.63	−16.13	5,800	64.75	32.06	62.75	1.37	10,100
86.00	1.50	37.50	−34.50	1,600	75.25	17.63	50.94	−15.69	5,900	64.50	32.38	63.00	1.75	10,200
85.75	1.87	37.81	−34.07	1,700	75.00	18.00	51.25	−15.25	6,000	64.25	32.69	63.25	2.13	10,300
85.50	2.25	38.13	−33.63	1,800	74.75	18.37	51.56	−14.82	6,100	64.00	33.00	63.50	2.50	10,400
85.25	2.63	38.44	−33.19	1,900	74.50	18.75	51.88	−14.38	6,200	63.75	33.31	63.75	2.87	10,500
85.00	3.00	38.75	−32.75	2,000	74.25	19.13	52.19	−13.94	6,300	63.50	33.63	64.00	3.25	10,600
84.75	3.37	39.06	−32.32	2,100	74.00	19.50	52.50	−13.50	6,400	63.25	33.94	64.25	3.63	10,700
84.50	3.75	39.38	−31.88	2,200	73.75	19.87	52.81	−13.07	6,500	63.00	34.25	64.50	4.00	10,800
84.25	4.13	39.69	−31.44	2,300	73.50	20.25	53.13	−12.63	6,600	62.75	34.56	64.75	4.37	10,900
84.00	4.50	40.00	−31.00	2,400	73.25	20.63	53.44	−12.19	6,700	62.50	34.88	65.00	4.75	11,000
83.75	4.87	40.31	−30.57	2,500	73.00	21.00	53.75	−11.75	6,800	62.25	35.19	65.25	5.13	11,100
83.50	5.25	40.63	−30.13	2,600	72.75	21.37	54.06	−11.32	6,900	62.00	35.50	65.50	5.50	11,200
83.25	5.63	40.94	−29.69	2,700	72.50	21.75	54.38	−10.88	7,000	61.75	35.81	65.75	5.87	11,300
83.00	6.00	41.25	−29.25	2,800	72.25	22.13	54.69	−10.44	7,100	61.50	36.13	66.00	6.25	11,400
82.75	6.37	41.56	−28.82	2,900	72.00	22.50	55.00	−10.00	7,200	61.25	36.44	66.25	6.63	11,500
82.50	6.75	41.88	−28.38	3,000	71.75	22.87	55.31	−9.57	7,300	61.00	36.75	66.50	7.00	11,600
82.25	7.13	42.19	−27.94	3,100	71.50	23.25	55.63	−9.13	7,400	60.75	37.06	66.75	7.37	11,700
82.00	7.50	42.50	−27.50	3,200	71.25	23.63	55.94	−8.69	7,500	60.50	37.38	67.00	7.75	11,800
81.75	7.87	42.81	−27.07	3,300	71.00	24.00	56.25	−8.25	7,600	60.25	37.69	67.25	8.13	11,900
81.50	8.25	43.13	−26.63	3,400	70.75	24.37	56.56	−7.82	7,700	60.00	38.00	67.50	8.50	12,000
81.25	8.63	43.44	−26.19	3,500	70.50	24.75	56.88	−7.38	7,800	59.75	38.25	67.62	8.87	12,100
81.00	9.00	43.75	−25.75	3,600	70.25	25.13	57.19	−6.94	7,900	59.50	38.50	67.75	9.25	12,200
80.75	9.37	44.06	−25.32	3,700	70.00	25.50	57.50	−6.50	8,000	59.25	38.75	67.87	9.63	12,300
80.50	9.75	44.38	−24.88	3,800	69.75	25.81	57.75	−6.13	8,100	59.00	39.00	68.00	10.00	12,400
80.25	10.13	44.69	−24.44	3,900	69.50	26.13	58.00	−5.78	8,200	58.75	39.25	68.12	10.37	12,500
80.00	10.50	45.00	−24.00	4,000	69.25	26.44	58.25	−5.37	8,300	58.50	39.50	68.25	10.75	12,600
79.75	10.87	45.31	−23.57	4,100	69.00	26.75	58.50	−5.00	8,400	58.25	39.75	68.37	11.13	12,700
79.50	11.25	45.63	−23.13	4,200	68.75	27.06	58.75	−4.63	8,500	58.00	40.00	68.50	11.50	12,800

TABLE 2.—*Modified thermal mean constants for application in the interpretation of the a, w, and c requirements for geographic positions*—Continued

Isop.	*a*	*w*	*c*	*Alt.*	*Isop.*	*a*	*w*	*c*	*Alt.*	*Isop.*	*a*	*w*	*c*	*Alt.*
57.75	40.25	68.62	11.87	12,900	38.25	59.75	78.37	41.13	20,700	18.75	77.93	87.46	68.40	28,500
57.50	40.50	68.75	12.25	13,000	38.00	60.00	78.50	41.50	20,800	18.50	78.12	87.56	68.68	28,600
57.25	40.75	68.87	12.63	13,100	37.75	60.25	78.62	41.87	20,900	18.25	78.31	87.66	68.96	28,700
57.00	41.00	69.00	13.00	13,200	37.50	60.50	78.75	42.25	21,000	18.00	78.50	87.75	69.25	28,800
56.75	41.25	69.12	13.37	13,300	37.25	60.75	78.87	42.63	21,100	17.75	78.62	87.81	69.43	28,900
56.50	41.50	69.25	13.75	13,400	37.00	61.00	79.00	43.00	21,200	17.50	78.75	87.87	69.62	29,000
56.25	41.75	69.37	14.13	13,500	36.75	61.25	79.12	43.37	21,300	17.25	78.87	87.94	69.81	29,100
56.00	42.00	69.50	14.50	13,600	36.50	61.50	79.25	43.75	21,400	17.00	79.00	88.00	70.00	29,200
55.75	42.25	69.62	14.87	13,700	36.25	61.75	79.37	44.13	21,500	16.75	79.12	88.06	70.18	29,300
55.50	42.50	69.75	15.25	13,800	36.00	62.00	79.50	44.50	21,600	16.50	79.25	88.12	70.37	29,400
55.25	42.75	69.87	15.63	13,900	35.75	62.25	79.62	44.87	21,700	16.25	79.37	88.19	70.56	29,500
55.00	43.00	70.00	16.00	14,000	35.50	62.50	79.75	45.25	21,800	16.00	79.50	88.25	70.75	29,600
54.75	43.25	70.12	16.37	14,100	35.25	62.75	79.87	45.63	21,900	15.75	79.62	88.31	70.93	29,700
54.50	43.50	70.25	16.75	14,200	35.00	63.00	80.00	46.00	22,000	15.50	79.75	88.37	71.12	29,800
54.25	43.75	70.37	17.13	14,300	34.75	63.25	80.12	46.37	22,100	15.25	79.87	88.44	71.31	29,900
54.00	44.00	70.50	17.50	14,400	34.50	63.50	80.25	46.75	22,200	15.00	80.00	88.50	71.50	30,000
53.75	44.25	70.62	17.87	14,500	34.25	63.75	80.37	47.13	22,300	14.75	80.12	88.56	71.68	30,100
53.50	44.50	70.75	18.25	14,600	34.00	64.00	80.50	47.50	22,400	14.50	80.25	88.62	71.87	30,200
53.25	44.75	70.87	18.63	14,700	33.75	64.25	80.62	47.87	22,500	14.25	80.37	88.69	72.06	30,300
53.00	45.00	71.00	19.00	14,800	33.50	64.50	80.75	48.25	22,600	14.00	80.50	88.75	72.25	30,400
52.75	45.25	71.12	19.37	14,900	33.25	64.75	80.87	48.63	22,700	13.75	80.62	88.81	72.43	30,500
52.50	45.50	71.25	19.75	15,000	33.00	65.00	81.00	49.00	22,800	13.50	80.75	88.87	72.62	30,600
52.25	45.75	71.37	20.13	15,100	32.75	65.25	81.12	49.37	22,900	13.25	80.87	88.94	72.81	30,700
52.00	46.00	71.50	20.50	15,200	32.50	65.50	81.25	49.75	23,000	13.00	81.00	89.00	73.00	30,800
51.75	46.25	71.62	20.87	15,300	32.25	65.75	81.37	50.13	23,100	12.75	81.12	89.03	73.18	30,900
51.50	46.50	71.75	21.25	15,400	32.00	66.00	81.50	50.50	23,200	12.50	81.25	89.06	73.37	31,000
51.25	46.75	71.87	21.63	15,500	31.75	66.25	81.62	50.87	23,300	12.25	81.37	89.09	73.56	31,100
51.00	47.00	72.00	22.00	15,600	31.50	66.50	81.75	51.25	23,400	12.00	81.50	89.12	73.75	31,200
50.75	47.25	72.12	22.37	15,700	31.25	66.75	81.87	51.63	23,500	11.75	81.62	89.15	73.93	31,300
50.50	47.50	72.25	22.75	15,800	31.00	67.00	82.00	52.00	23,600	11.50	81.75	89.18	74.12	31,400
50.25	47.75	72.37	23.13	15,900	30.75	67.25	82.12	52.37	23,700	11.25	81.87	89.21	74.31	31,500
50.00	48.00	72.50	23.50	16,000	30.50	67.50	82.25	52.75	23,800	11.00	82.00	89.25	74.50	31,600
49.75	48.25	72.62	23.87	16,100	30.25	67.75	82.37	53.13	23,900	10.75	82.12	89.28	74.68	31,700
49.50	48.50	72.75	24.25	16,200	30.00	68.00	82.50	53.50	24,000	10.50	82.25	89.31	74.87	31,800
49.25	48.75	72.87	24.63	16,300	29.75	68.25	82.62	53.87	24,100	10.25	82.37	89.34	75.06	31,900
49.00	49.00	73.00	25.00	16,400	29.50	68.50	82.75	54.25	24,200	10.00	82.50	89.37	75.25	32,000
48.75	49.25	73.12	25.37	16,500	29.25	68.75	82.87	54.63	24,300	9.75	82.62	89.40	75.43	32,100
48.50	49.50	73.25	25.75	16,600	29.00	69.00	83.00	55.00	24,400	9.50	82.75	89.43	75.62	32,200
48.25	49.75	73.37	26.13	16,700	28.75	69.25	83.12	55.37	24,500	9.25	82.87	89.46	75.81	32,300
48.00	50.00	73.50	26.50	16,800	28.50	69.50	83.25	55.75	24,600	9.00	83.00	89.50	76.00	32,400
47.75	50.25	73.62	26.87	16,900	28.25	69.75	83.37	56.13	24,700	8.75	83.12	89.52	76.18	32,500
47.50	50.50	73.75	27.25	17,000	28.00	70.00	83.50	56.50	24,800	8.50	83.25	89.54	76.37	32,600
47.25	50.75	73.87	27.63	17,100	27.75	70.25	83.62	56.87	24,900	8.25	83.37	89.56	76.56	32,700
47.00	51.00	74.00	28.00	17,200	27.50	70.50	83.75	57.25	25,000	8.00	83.50	89.58	76.75	32,800
46.75	51.25	74.12	28.37	17,300	27.25	70.75	83.87	57.63	25,100	7.75	83.56	89.60	76.93	32,900
46.50	51.50	74.25	28.75	17,400	27.00	71.00	84.00	58.00	25,200	7.50	83.62	89.62	77.12	33,000
46.25	51.75	74.37	29.13	17,500	26.75	71.25	84.12	58.37	25,300	7.25	83.68	89.64	77.31	33,100
46.00	52.00	74.50	29.50	17,600	26.50	71.50	84.25	58.75	25,400	7.00	83.75	89.66	77.50	33,200
45.75	52.25	74.62	29.87	17,700	26.25	71.75	84.37	59.13	25,500	6.75	83.81	89.68	77.62	33,300
45.50	52.50	74.75	30.25	17,800	26.00	72.00	84.50	59.50	25,600	6.50	83.87	89.70	77.75	33,400
45.25	52.75	74.87	30.63	17,900	25.75	72.25	84.62	59.87	25,700	6.25	83.93	89.72	77.87	33,500
45.00	53.00	75.00	31.00	18,000	25.50	72.50	84.75	60.25	25,800	6.00	84.00	89.74	78.00	33,600
44.75	53.25	75.12	31.37	18,100	25.25	72.75	84.87	60.63	25,900	5.75	84.06	89.76	78.12	33,700
44.50	53.50	75.25	31.75	18,200	25.00	73.00	85.00	61.00	26,000	5.50	84.12	89.78	78.25	33,800
44.25	53.75	75.37	32.13	18,300	24.75	73.25	85.12	61.37	26,100	5.25	84.18	89.80	78.37	33,900
44.00	54.00	75.50	32.50	18,400	24.50	73.50	85.25	61.75	26,200	5.00	84.25	89.82	78.50	34,000
43.75	54.25	75.62	32.87	18,500	24.25	73.75	85.37	62.13	26,300	4.75	84.31	89.83	78.62	34,100
43.50	54.50	75.75	33.25	18,600	24.00	74.00	85.50	62.50	26,400	4.50	84.37	89.84	78.75	34,200
43.25	54.75	75.87	33.63	18,700	23.75	74.18	85.59	62.78	26,500	4.25	84.43	89.85	78.87	34,300
43.00	55.00	76.00	34.00	18,800	23.50	74.37	85.68	63.06	26,600	4.00	84.50	89.86	79.00	34,400
42.75	55.25	76.12	34.37	18,900	23.25	74.56	85.78	63.34	26,700	3.75	84.56	89.87	79.12	34,500
42.50	55.50	76.25	34.75	19,000	23.00	74.75	85.87	63.62	26,800	3.50	84.62	89.88	79.25	34,600
42.25	55.75	76.37	35.13	19,100	22.75	74.93	85.96	63.90	26,900	3.25	84.68	89.89	79.37	34,700
42.00	56.00	76.50	35.50	19,200	22.50	75.12	86.06	64.18	27,000	3.00	84.75	89.90	79.50	34,800
41.75	56.25	76.62	35.87	19,300	22.25	75.31	86.16	64.46	27,100	2.75	84.81	89.91	79.62	34,900
41.50	56.50	76.75	36.25	19,400	22.00	75.50	86.25	64.75	27,200	2.50	84.87	89.92	79.75	35,000
41.25	56.75	76.87	36.63	19,500	21.75	75.68	86.34	65.03	27,300	2.25	84.93	89.93	79.87	35,100
41.00	57.00	77.00	37.00	19,600	21.50	75.87	86.43	65.31	27,400	2.00	85.00	89.94	80.00	35,200
40.75	57.25	77.12	37.37	19,700	21.25	76.06	86.53	65.59	27,500	1.75	85.06	89.95	80.12	35,300
40.50	57.50	77.25	37.75	19,800	21.00	76.25	86.62	65.87	27,600	1.50	85.12	89.96	80.25	35,400
40.25	57.75	77.37	38.13	19,900	20.75	76.43	86.71	66.15	27,700	1.25	85.18	89.97	80.37	35,500
40.00	58.00	77.50	38.50	20,000	20.50	76.62	86.81	66.43	27,800	1.00	85.25	89.98	80.50	35,600
39.75	58.25	77.62	38.87	20,100	20.25	76.81	86.91	66.71	27,900	.75	85.31	89.99	80.62	35,700
39.50	58.50	77.75	39.25	20,200	20.00	77.00	87.00	67.00	28,000	.50	85.37	89.99	80.75	35,800
39.25	58.75	77.87	39.63	20,300	19.75	77.18	87.09	67.28	28,100	.25	85.43	90.00	80.87	35,900
39.00	59.00	78.00	40.00	20,400	19.50	77.37	87.18	67.56	28,200	.00	85.50	90.00	81.00	36,000
38.75	59.25	78.12	40.37	20,500	19.25	77.56	87.28	67.84	28,300					
38.50	59.50	78.25	40.75	20,600	19.00	77.75	87.37	68.12	28,400					

EXPLANATION OF TABLE 2

The purpose of this table is to provide requirement constants of the bioclimatic law in degrees Fahrenheit in which *a* gives the annual mean, *w* the mean of the warmest month, and *c* the mean of the coldest month for the sea-level isophanes from the north and south polar isophanes 90 to the equatorial isophane 0.

Alt. gives the equivalent altitude above, to the given isophanes at, sea level from sea level on the polar isophane 90 and above the other sea-level isophanes to the equatorial isophane 0, as computed from sea level (0) at the poles by the standard rate of 100 feet to each 0.25° isophane. Thus the given altitude constant for a given isophane is the alpine equivalent to sea level at the poles, e. g., 18,800 feet on isophane 43, or 36,000 feet on the equatorial isophane.

This table is utilized in bioclimatics to determine, by the variations of the *a*, *w*, or *c* position records from their constants, the average temperature to be expected within a given area or region represented by one or more record positions, but without regard to its relative effective influence, zones, etc., which are determined from table 3. In other words, this table serves specifically for the interpretation of position temperatures to be expected within a given area.

TABLE 3.—*Modified thermal mean constants for application in the interpretation of zonal constants and other effects for geographic positions*

Zones		Isop.	Fahrenheit			Centigrade		
Ma	*Mi*		*a*	*w*	*c*	*a*	*w*	*c*
		90.00	−6.25	29.00	−41.50	−21.3	−1.7	−40.8
I	+1	89.75	−5.90	29.25	−41.06	−21.1	−1.5	−40.6
		89.50	−5.56	29.50	−40.63	−20.9	−1.4	−40.3
		89.25	−5.22	29.75	−40.19	−20.7	−1.2	−40.1
	+.1	89.00	−4.87	30.00	−39.75	−20.5	−1.1	−39.9
		88.75	−4.52	30.25	−39.32	−20.3	−1.0	−39.6
		88.50	−4.18	30.50	−38.88	−20.1	−.8	−39.4
		88.25	−3.84	30.75	−38.44	−19.9	−.7	−39.1
		88.00	−3.50	31.00	−38.00	−19.7	−.6	−38.9
		87.75	−3.15	31.25	−37.57	−19.5	−.4	−38.6
		87.50	−2.81	31.50	−37.13	−19.3	−.3	−38.4
	.1	87.25	−2.47	31.75	−36.69	−19.2	−.1	−38.2
		87.00	−2.12	32.00	−36.25	−19.0	.0	−37.9
		86.75	−1.77	32.25	−35.82	−18.8	+.1	−37.7
		86.50	−1.43	32.50	−35.38	−18.6	.3	−37.4
		86.25	−1.09	32.75	−34.94	−18.4	.4	−37.2
	−.1	86.00	−.75	33.00	−34.50	−18.2	.6	−36.9
		85.75	−.40	33.25	−34.06	−18.0	.7	−36.7
		85.50	−.06	33.50	−33.63	−17.8	.8	−36.5
	−1	85.25	+.28	33.75	−33.19	−17.6	1.0	−36.2
		85.00	+.63	34.00	−32.75	−17.4	1.1	−36.0
		84.75	+.97	34.25	−32.32	−17.2	1.2	−35.7
		84.50	+1.31	34.50	−31.88	−17.0	1.4	−35.5
		84.25	1.65	34.75	−31.44	−16.9	1.5	−35.2
	+2	84.00	2.00	35.00	−31.00	−16.7	1.7	−35.0
		83.75	2.35	35.25	−30.57	−16.5	1.8	−34.8
		83.50	2.69	35.50	−30.13	−16.3	1.9	−34.5
		83.25	3.03	35.75	−29.69	−16.1	2.1	−34.3
		83.00	3.37	36.00	−29.25	−15.9	2.2	−34.0
		82.75	3.72	36.25	−28.82	−15.7	2.4	−33.8
		82.50	4.06	36.50	−28.38	−15.5	2.5	−33.5
	+.2	82.25	4.40	36.75	−27.94	−15.3	2.6	−33.3
		82.00	4.75	37.00	−27.50	−15.1	2.8	−33.1
		81.75	5.10	37.25	−27.06	−14.9	2.9	−32.8
		81.50	5.44	37.50	−26.63	−14.8	3.1	−32.6
		81.25	5.78	37.75	−26.19	−14.6	3.2	−32.3
		81.00	6.12	38.00	−25.75	−14.4	3.3	−32.1
		80.75	6.47	38.25	−25.32	−14.2	3.5	−31.8
		80.50	6.81	38.50	−24.88	−14.0	3.6	−31.6
		80.25	7.15	38.75	−24.44	−13.8	3.8	−31.4
	.2	80.00	7.50	39.00	−24.00	−13.6	3.9	−31.1
		79.75	7.85	39.25	−23.57	−13.4	4.0	−30.9
		79.50	8.19	39.50	−23.13	−13.2	4.2	−30.6
		79.25	8.53	39.75	−22.69	−13.0	4.3	−30.4
		79.00	8.87	40.00	−22.25	−12.8	4.4	−30.1
		78.75	9.22	40.25	−21.82	−12.7	4.6	−29.9
		78.50	9.56	40.50	−21.38	−12.5	4.7	−29.7
		78.25	9.90	40.75	−20.94	−12.3	4.9	−29.4
		78.00	10.25	41.00	−20.50	−12.1	5.0	−29.2
		77.75	10.60	41.25	−20.06	−11.9	5.1	−28.9
	−.2	77.50	10.94	41.50	−19.63	−11.7	5.3	−28.7
		77.25	11.28	41.75	−19.19	−11.5	5.4	−28.4
		77.00	11.62	42.00	−18.75	−11.3	5.6	−28.2
		76.75	11.98	42.25	−18.32	−11.1	5.7	−28.0
		76.50	12.32	42.50	−17.88	−10.9	5.8	−27.7
		76.25	12.66	42.75	−17.44	−10.7	6.0	−27.5
		76.00	13.00	43.00	−17.00	−10.6	6.1	−27.2
	−2	75.75	13.35	43.25	−16.57	−10.4	6.2	−27.0
		75.50	13.69	43.50	−16.13	−10.2	6.4	−26.7
		75.25	14.03	43.75	−15.69	−10.0	6.5	−26.5
		75.00	14.37	44.00	−15.25	−9.8	6.7	−26.3
		74.75	14.72	44.25	−14.82	−9.6	6.8	−26.0
		74.50	15.06	44.50	−14.38	−9.4	6.9	−25.8
	+3	74.25	15.40	44.75	−13.94	−9.2	7.1	−25.5
		74.00	15.75	45.00	−13.50	−9.0	7.2	−25.3
		73.75	16.10	45.25	−13.06	−8.8	7.4	−25.0
		73.50	16.44	45.50	−12.63	−8.6	7.5	−24.8
		73.25	16.78	45.75	−12.19	−8.5	7.6	−24.5
	+.3	73.00	17.12	46.00	−11.75	−8.3	7.8	−24.3
		72.75	17.47	46.25	−11.32	−8.1	7.9	−24.1
		72.50	17.81	46.50	−10.88	−7.9	8.1	−23.8
		72.25	18.15	46.75	−10.44	−7.7	8.2	−23.6
		72.00	18.50	47.00	−10.00	−7.5	8.3	−23.3
		71.75	18.85	47.25	−9.57	−7.3	8.5	−23.1
		71.50	19.19	47.50	−9.13	−7.1	8.6	−22.8
		71.25	19.53	47.75	−8.69	−6.9	8.8	−22.6
		71.00	19.87	48.00	−8.25	−6.7	8.9	−22.4
	.3	70.75	20.22	48.25	−7.82	−6.5	9.0	−22.1
		70.50	20.56	48.50	−7.38	−6.4	9.2	−21.9
		70.25	20.90	48.75	−6.94	−6.2	9.3	−21.6
		70.00	21.25	49.00	−6.50	−6.0	9.4	−21.4
		69.75	21.57	49.25	−6.12	−5.8	9.6	−21.2
		69.50	21.88	49.50	−5.78	−5.6	9.7	−21.0
		69.25	22.19	49.75	−5.37	−5.5	9.9	−20.8
		69.00	22.50	50.00	−5.00	−5.3	10.0	−20.6
		68.75	22.81	50.25	−4.62	−5.1	10.1	−20.3
	−.3	68.50	23.13	50.50	−4.25	−4.9	10.3	−20.1
		68.25	23.44	50.75	−3.87	−4.8	10.4	−19.9
		68.00	23.75	51.00	−3.50	−4.6	10.6	−19.7
		67.75	24.06	51.25	−3.12	−4.4	10.7	−19.5
		67.50	24.38	51.50	−2.75	−4.2	10.8	−19.3
	−3	67.25	24.69	51.75	−2.37	−4.1	11.0	−19.1
		67.00	25.00	52.00	−2.00	−3.9	11.1	−18.9
		66.75	25.31	52.25	−1.62	−3.7	11.3	−18.7
		66.50	25.63	52.50	−1.25	−3.5	11.4	−18.5
		66.25	25.94	52.75	−.87	−3.4	11.5	−18.3
	+4	66.00	26.25	53.00	−.50	−3.2	11.7	−18.1
		65.75	26.56	53.25	−.12	−3.0	11.8	−17.8
		65.50	26.88	53.50	+.25	−2.8	11.9	−17.6
	+.4	65.25	27.19	53.75	+.63	−2.7	12.1	−17.4
		65.00	27.50	54.00	+1.00	−2.5	12.2	−17.2
		64.75	27.81	54.25	1.37	−2.3	12.4	−17.0

Zones		Isop.	Fahrenheit			Centigrade		
Ma	*Mi*		*a*	*w*	*c*	*a*	*w*	*c*
I		64.50	28.13	54.50	1.75	−2.1	12.5	−16.8
		64.25	28.44	54.75	2.13	−2.0	12.6	−16.6
		64.00	28.75	55.00	2.50	−1.8	12.8	−16.4
		63.75	29.06	55.25	2.87	−1.6	12.9	−16.2
		63.50	29.38	55.50	3.25	−1.5	13.1	−16.0
	.4	63.25	29.69	55.75	3.63	−1.3	13.2	−15.8
		63.00	30.00	56.00	4.00	−1.1	13.3	−15.6
		62.75	30.31	56.25	4.37	−.9	13.5	−15.4
		62.50	30.63	56.50	4.75	−.8	13.6	−15.1
		62.25	30.94	56.75	5.13	−.6	13.8	−14.9
		62.00	31.25	57.00	5.50	−.4	13.9	−14.7
		61.75	31.56	57.25	5.87	−.2	14.0	−14.5
	−.4	61.50	31.88	57.50	6.25	−.1	14.2	−14.3
		61.25	32.19	57.75	6.63	+.1	14.3	−14.1
		61.00	32.50	58.00	7.00	+.3	14.4	−13.9
		60.75	32.81	58.25	7.37	+.5	14.6	−13.7
	−4	60.50	33.13	58.50	7.75	+.6	14.7	−13.5
		60.25	33.44	58.75	8.13	+.8	14.9	−13.3
		60.00	33.75	59.00	8.50	+1.0	15.0	−13.1
II	+1	59.75	34.06	59.25	8.87	1.1	15.1	−12.9
		59.50	34.38	59.50	9.25	1.3	15.3	−12.6
	+.1	59.25	34.69	59.75	9.63	1.5	15.4	−12.4
		59.00	35.00	60.00	10.00	1.7	15.6	−12.2
		58.75	35.31	60.25	10.37	1.8	15.7	−12.0
	.1	58.50	35.63	60.50	10.75	2.0	15.8	−11.8
		58.25	35.94	60.75	11.13	2.2	16.0	−11.6
		58.60	36.25	61.00	11.50	2.4	16.1	−11.4
	−.1	57.75	36.56	61.25	11.87	2.5	16.3	−11.2
		57.50	36.88	61.50	12.25	2.7	16.4	−11.0
	−1	57.25	37.19	61.75	12.63	2.9	16.5	−10.8
		57.00	37.50	62.00	13.00	3.1	16.7	−10.6
		56.75	37.81	62.25	13.37	3.2	16.8	−10.4
		56.50	38.13	62.50	13.75	3.4	16.9	−10.1
	+2	56.25	38.44	62.75	14.13	3.6	17.1	−9.9
		56.00	38.75	63.00	14.50	3.8	17.2	−9.7
		55.75	39.06	63.25	14.87	3.9	17.4	−9.5
		55.50	39.38	63.50	15.25	4.1	17.5	−9.3
	+.2	55.25	39.69	63.75	15.63	4.3	17.6	−9.1
		55.00	40.00	64.00	16.00	4.4	17.8	−8.9
		54.75	40.31	64.25	16.37	4.6	17.9	−8.7
		54.50	40.63	64.50	16.75	4.8	18.1	−8.5
		54.25	40.94	64.75	17.13	5.0	18.2	−8.3
		54.00	41.25	65.00	17.50	5.1	18.3	−8.1
	.2	53.75	41.56	65.25	17.87	5.3	18.5	−7.9
		53.50	41.88	65.50	18.25	5.5	18.6	−7.6
		53.25	42.19	65.75	18.63	5.7	18.7	−7.4
		53.00	42.50	66.00	19.00	5.8	18.9	−7.2
		52.75	42.81	66.25	19.37	6.0	19.0	−7.0
		52.50	43.13	66.50	19.75	6.2	19.2	−6.8
	−.2	52.25	43.44	66.75	20.13	6.4	19.3	−6.6
		52.00	43.75	67.00	20.50	6.5	19.4	−6.4
		51.75	44.06	67.25	20.87	6.7	19.6	−6.2
		51.50	44.38	67.50	21.25	6.9	19.7	−6.0
	−2	51.25	44.69	67.75	21.63	7.1	19.9	−5.8
		51.00	45.00	68.00	22.00	7.2	20.0	−5.6
	+3	50.75	45.31	68.25	22.37	7.4	20.1	−5.4
		50.50	45.63	68.50	22.75	7.6	20.3	−5.1
	+.3	50.25	45.94	68.75	23.13	7.7	20.4	−4.9
		50.00	46.25	69.00	23.50	7.9	20.6	−4.7
		49.75	46.56	69.25	23.87	8.1	20.7	−4.5
	.3	49.50	46.88	69.50	24.25	8.3	20.8	−4.3
		49.25	47.19	69.75	24.63	8.4	21.0	−4.1
		49.00	47.50	70.00	25.00	8.6	21.1	−3.9
	−.3	48.75	47.81	70.25	25.37	8.8	21.3	−3.7
		48.50	48.13	70.50	25.75	9.0	21.4	−3.5
	−3	48.25	48.44	70.75	26.13	9.1	21.5	−3.3
		48.00	48.75	71.00	26.50	9.3	21.7	−3.1
		47.75	49.06	71.25	26.87	9.5	21.8	−2.9
	+4	47.50	49.38	71.50	27.25	9.7	21.9	−2.6
		47.25	49.69	71.75	27.63	9.8	22.1	−2.4
		47.00	50.00	72.00	28.00	10.0	22.2	−2.2
	+.4	46.75	50.31	72.25	28.37	10.2	22.4	−2.0
		46.50	50.63	72.50	28.75	10.4	22.5	−1.8
		46.25	50.94	72.75	29.13	10.5	22.6	−1.6
		46.00	51.25	73.00	29.50	10.7	22.8	−1.4
		45.75	51.56	73.25	29.87	10.9	22.9	−1.2
	.4	45.50	51.88	73.50	30.25	11.0	23.1	−1.0
		45.25	52.19	73.75	30.63	11.2	23.2	−.8
		45.00	52.50	74.00	31.00	11.4	23.3	−.6
		44.75	52.81	74.25	31.37	11.6	23.5	−.4
		44.50	53.13	74.50	31.87	11.7	23.6	−.1
		44.25	53.44	74.75	32.13	11.9	23.7	+.1
	−.4	44.00	53.75	75.00	32.50	12.1	23.9	.3
		43.75	54.16	75.25	32.87	12.3	24.0	.5
		43.50	54.38	75.50	33.25	12.4	24.2	.7
	−4	43.25	54.69	75.75	33.63	12.6	24.3	.9
		43.00	55.00	76.00	34.00	12.8	24.4	1.1
		42.75	55.31	76.25	34.37	13.0	24.6	1.3
	+5	42.50	55.62	76.50	34.75	13.1	24.7	1.5
	+.5	42.25	55.94	76.75	35.12	13.3	24.9	1.7
		42.00	56.25	77.00	35.50	13.5	25.0	1.9
		41.75	56.56	77.25	35.88	13.6	25.1	2.2
		41.50	56.87	77.50	36.25	13.8	25.3	2.4
	.5	41.25	57.18	77.75	36.62	14.0	25.4	2.6
		41.00	57.50	78.00	37.00	14.2	25.6	2.8
		40.75	57.80	78.22	37.38	14.3	25.7	3.0
	−.5	40.50	58.10	78.45	37.75	14.5	25.8	3.2
	−5	40.25	58.40	78.67	38.12	14.7	25.9	3.4
		40.00	58.70	78.90	38.50	14.8	26.1	3.6
		39.75	59.00	79.12	38.88	15.0	26.2	3.8
	+6	39.50	59.30	79.34	39.25	15.2	26.3	4.0
		39.25	59.60	79.57	39.62	15.3	26.4	4.2
		39.00	59.90	79.80	40.00	15.5	26.6	4.4

TABLE 3.—*Modified thermal mean constants for application in the interpretation of zonal constants and other effects for geographic positions*—Continued

Zones Ma	Zones Mi	Isop.	Fahrenheit a	Fahrenheit w	Fahrenheit c	Centigrade a	Centigrade w	Centigrade c
II		38.75	60.20	80.02	40.38	15.7	26.7	4.7
		38.50	60.50	80.24	40.75	15.8	26.8	4.9
	+.6	38.25	60.80	80.46	41.12	16.0	26.9	5.1
		38.00	61.10	80.70	41.50	16.2	27.1	5.3
		37.75	61.39	80.90	41.88	16.3	27.2	5.5
		37.50	61.68	81.10	42.25	16.5	27.3	5.7
		37.25	61.97	81.30	42.62	16.7	27.4	5.9
		37.00	62.25	81.50	43.00	16.8	27.5	6.1
	.6	36.75	62.54	81.70	43.38	17.0	27.6	6.3
		36.50	62.83	81.90	43.75	17.1	27.7	6.5
		36.25	63.12	82.10	44.12	17.3	27.8	6.7
		36.00	63.40	82.30	44.50	17.4	27.9	6.9
		35.75	63.69	82.50	44.88	17.6	28.1	7.2
		35.50	63.98	82.70	45.25	17.8	28.2	7.4
	−.6	35.25	64.27	82.90	45.62	17.9	28.3	7.6
		35.00	64.55	83.10	46.00	18.1	28.4	7.8
		34.75	64.84	83.30	46.36	18.2	28.5	8.0
		34.50	65.13	83.50	46.75	18.4	28.6	8.2
	−6	34.25	65.42	83.70	47.12	18.6	28.7	8.4
		34.00	65.70	83.90	47.50	18.7	28.8	8.6
		33.75	65.99	84.10	47.88	18.9	28.9	8.8
	+7	33.50	66.28	84.30	48.25	19.0	29.1	9.0
		33.25	66.57	84.50	48.62	19.2	29.2	9.2
		33.00	66.85	84.70	49.00	19.4	29.3	9.4
	+.7	32.75	67.10	84.82	49.38	19.5	29.3	9.7
		32.50	67.35	84.95	49 75	19.6	29.4	9.9
		32.25	67.60	85.08	50.12	19.8	29.5	10.1
		32.00	67.85	85 20	50.50	19.9	29.6	10.3
	.7	31.75	68.10	85.32	50.88	20.1	29.6	10.5
		31.50	68.35	85.45	51.25	20.2	29.7	10.7
		31.25	68.60	85.58	51.62	20.3	29.8	10.9
	−.7	31.00	68.85	85.70	52.00	20.5	29.8	11.1
		30.75	69.10	85.82	52.38	20.6	29.9	11.3
		30.50	69.35	85.95	52.75	20.8	30.0	11.5
	−7	30.25	69.60	86.08	53.12	20.9	30.0	11.7
		30.00	69.85	86.20	53.50	21.0	30.1	11.9
III		29.75	70.10	86.32	53.88	21.2	30.2	12.2
		29.50	70.35	86.45	54.25	21.3	30.3	12.4
	+1	29.25	70.60	86.58	54.62	21.4	30.3	12.6
		29.00	70.85	86.70	55.00	21.6	30.4	12.8
		28.75	71.10	86.82	55.38	21.7	30.5	13.0
		28.50	71.35	86.95	55.75	21.9	30.5	13.2
	+.1	28.25	71.60	87.08	56.12	22.0	30.6	13.4
		28.00	71.85	87.20	56.50	22.1	30.7	13.6
		27.75	72.10	87.32	56.88	22.3	30.7	13.8
		27.50	72.35	87.45	57.25	22.4	30.8	14.0
		27.25	72.60	87.58	57.62	22.6	30.9	14.2
		27.00	72.85	87.70	58.00	22.7	30.9	14.4
	.1	26.75	73.07	87.77	58.38	22.8	31.0	14.7
		26.50	73.29	87.85	58.75	22.9	31.0	14.9
		26.25	73.51	87.93	59.12	23.1	31.1	15.1
		26.00	73.75	88.00	59.50	23.2	31.1	15.3
		25.75	73.97	88.07	59.88	23.3	31.2	15.5
		25.50	74.20	88.15	60.25	23.4	31.2	15.7
	−.1	25.25	74.43	88.23	60.62	23.6	31.2	15.9
		25.00	74.65	88.30	61.00	23.7	31.3	16.1
		24.75	74.85	88.37	61.32	23.8	31.3	16.3
		24.50	75.05	88.45	61.65	23.9	31.4	16.5
	−1	24.25	75.25	88.53	61.98	24.0	31.4	16.7
		24.00	75.45	88.60	62.30	24.1	31.4	16.8
		23.75	75.65	88.67	62.62	24.2	31.5	17.0
		23.50	75.85	88.75	62.95	24.4	31.5	17.2
		23.25	76.05	88.83	63.28	24.5	31.6	17.4
	+2	23.00	76.25	88.90	63.60	24.6	31.6	17.6
		22.75	76.44	88.96	63.91	24.7	31.6	17.7
		22.50	76.62	89.03	64.22	24.8	31.7	17.9
		22.25	76.81	89.09	64.53	24.9	31.7	18.1
		22.00	77.00	89.15	64.85	25.0	31.8	18.3
		21.75	77.18	89.20	65.16	25.1	31.8	18.4
	+.2	21.50	77.36	89.25	65.48	25.2	31.8	18.6
		21.25	77.54	89.30	65.79	25.3	31.8	18.8
		21.00	77.72	89.35	66.10	25.4	31.9	18.9
		20.75	77.89	89.38	66.41	25.5	31.9	19.1
		20.50	78.07	89.42	66.72	25.6	31.9	19.3
	.2	20.25	78.24	89.46	67.03	25.7	31.9	19.5
		20.00	78.42	89.50	67.35	25.8	31.9	19.6
		19.75	78.58	89.52	67.65	25.9	32.0	19.8
		19.50	78.75	89.55	67.95	26.0	32.0	20.0
III		19.25	78.91	89.58	68.25	26.1	32.0	20.1
		19.00	79.07	89.60	68.55	26.2	32.0	20.3
		18.75	79.22	89.61	68.85	26.2	32.0	20.5
	.2	18.50	79.38	89.62	69.15	26.3	32.0	20.6
		18.25	79.54	89.64	69.45	26.4	32.0	20.8
		18.00	79.70	89.65	69.75	26.5	32.0	21.0
		17.75	79.86	89.66	70.05	26.6	32.0	21.1
		17.50	80.02	89.67	70.35	26.7	32.0	21.3
		17.25	80.17	89.68	70.65	26.8	32.0	21.5
	−.2	17.00	80.32	89.69	70.95	26.8	32.0	21.6
		16.75	80.47	89.70	71.25	26.9	32.1	21.8
		16.50	80.63	89.71	71.55	27.0	32.1	22.0
		16.25	80.78	89.72	71.85	27.1	32.1	22.1
		16.00	80.94	89.73	72.15	27.2	32.1	22.3
		15.75	81.10	89.74	72.45	27.3	32.1	22.5
	−2	15.50	81.26	89.75	72.75	27.4	32.1	22.6
		15.25	81.41	89.76	73.05	27.4	32.1	22.8
		15.00	81.56	89.77	73.35	27.5	32.1	23.0
		14.75	81.71	89.77	73.65	27.6	32.1	23.1
		14.50	81.86	89.78	73.95	27.7	32.1	23.3
		14.25	82.02	89.78	74.25	27.8	32.1	23.5
		14.00	82.17	89.79	74.55	27.9	32.1	23.6
		13.75	82.32	89.79	74.89	28.0	32.1	23.8
	+3	13.50	82.47	89.80	75.12	28.0	32.1	24.0
		13.25	82.61	89.80	75.41	28.1	32.1	24.1
		13.00	82.76	89.81	75.70	28.2	32.1	24.3
		12.75	82.90	89.81	75.99	28.3	32.1	24.4
		12.50	83.05	89.82	76.28	28.4	32.1	24.6
		12.25	83.20	89.82	76.57	28.4	32.1	24.8
		12.00	83.34	89.83	76.85	28.5	32.1	24.9
		11.75	83.48	89.83	77.12	28.6	32.1	25.1
		11.50	83.62	89.84	77.40	28.7	32.1	25.2
	+.3	11.25	83.76	89.84	77.68	28.8	32.1	25.4
		11.00	83.90	89.85	77.95	28.8	32.1	25.5
		10.75	84.03	89.85	78.21	28.9	32.1	25.7
		10.50	84.17	89.86	78.48	29.0	32.1	25.8
		10.25	84.30	89.86	78.74	29.1	32.1	26.0
		10.00	84.43	89.87	79.00	29.1	32.1	26.1
		9.75	84.56	89.87	79.25	29.2	32.1	26.2
		9.50	84.69	89.88	79.50	29.3	32.2	26.4
		9.25	84.82	89.88	79.75	29.3	32.2	26.5
	.3	9.00	84.95	89.89	80.00	29.4	32.2	26.7
		8.75	85.07	89.89	80.25	29.5	32.2	26.8
		8.50	85.20	89.90	80.50	29.6	32.2	26.9
		8.25	85.33	89.90	80.75	29.6	32.2	27.1
		8.00	85.46	89.91	81.00	29.7	32.2	27.2
		7.75	85.58	89.91	81.24	29.8	32.2	27.4
		7.50	85.70	89.92	81.48	29.8	32.2	27.5
		7.25	85.82	89.92	81.72	29.9	32.2	27.6
	−.3	7.00	85.94	89.93	81.95	30.0	32.2	27.8
		6.75	86.05	89.93	82.17	30.0	32.2	27.9
		6.50	86.17	89.93	82.40	30.1	32.2	28.0
		6.25	86.29	89.93	82.63	30.2	32.2	28.1
		6.00	86.40	89.94	82.85	30.2	32.2	28.2
		5.75	86.51	89.94	83.07	30.3	32.2	28.4
	−3	5.50	86.63	89.94	83.30	30.4	32.2	28.5
		5.25	86.74	89.94	83.53	30.4	32.2	28.6
		5.00	86.85	89.95	83.75	30.5	32.2	28.7
		4.75	86.96	89.95	83.96	30.5	32.2	28.9
	+4	4.50	87.07	89.95	84.18	30.6	32.2	29.0
		4.25	87.18	89.95	84.39	30.7	32.2	29.1
		4.00	87.29	89.96	84.60	30.7	32.2	29.2
	+.4	3.75	87.40	89.96	84.81	30.8	32.2	29.3
		3.50	87.51	89.96	85.02	30.8	32.2	29.5
		3.25	87.62	89.97	85.23	30.9	32.2	29.6
		3.00	87.72	89.97	85.45	31.0	32.2	29.7
		2.75	87.83	89.97	85.66	31.0	32.2	29.8
		2.50	87.94	89.97	85.87	31.1	32.2	29.9
	.4	2.25	88.05	89.98	86.08	31.1	32.2	30.0
		2.00	88.15	89.98	86.30	31.2	32.2	30.2
		1.75	88.26	89.98	86.51	31.3	32.2	30.3
		1.50	88.37	89.98	86.72	31.3	32.2	30.4
		1.25	88.48	89.99	86.93	31.4	32.2	30.5
	−.4	1.00	88.58	89.99	87.15	31.4	32.2	30.6
		.75	88.69	89.99	87.36	31.5	32.2	30.8
		.50	88.79	89.99	87.57	31.6	32.2	30.9
	−4	.25	88.90	90.00	87.78	31.6	32.2	31.0
		.00	89.00	90.00	88.00	31.7	32.2	31.1

Schedule of modified unit constant rates in degrees Fahrenheit for 1° isophanes

a		w		c	
Isophanes	Rate	Isophanes	Rate	Isophanes	Rate
90.00–70.00	1.375	90.00–41.00	1.00	90.00–70.00	1.75
70.00–41.00	1.25	41.00–38.00	.90	70.00–25.00	1.50
41.00–38.00	1.20	38.00–33.00	.80	25.00–23.00	1.30
38.00–33.00	1.15	33.00–27.00	.50	23.00–20.00	1.25
33.00–27.00	1.00	27.00–23.00	.30	20.00–14.00	1.20
27.00–25.00	.90	23.00–22.00	.25	14.00–12.00	1.15
25.00–23.00	.80	22.00–21.00	.20	12.00–11.00	1.10
23.00–22.00	.75	21.00–20.00	.15	11.00–10.00	1.05
22.00–21.00	.72	20.00–19.00	.10	10.00– 8.00	1.00
21.00–20.00	.70	19.00–18.00	.05	8.00– 7.00	.95
20.00–19.00	.65	18.00–15.00	.04	7.00– 5.00	.90
19.00–18.00	.63	15.00– 7.00	.02	5.00– .00	.85
18.00–15.00	.62	7.00– .00	.01	90.00– .00	1.43+
15.60–14.00	.61	90.00– .00	.66+		
14.00–13.00	.59				
13.00–12.00	.58				
12.00–11.00	.56				
11.00–10.00	.53				
10.00– 9.00	.52				
9.00– 8.00	.51				
8.00– 7.00	.48				
7.00– 6.00	.46				
6.00– 5.00	.45				
5.00– 4.00	.44				
4.00– 1.00	.43				
1.00– .00	.42				
90.00– .00	1.05+				

HISTORICAL

September 13, 1920, original draft of table, Hopkins; June 26, 1921, revised from isophane 43 to 0, Hopkins; July 13, 1921, revised from isophane 43 to 90, Hopkins; July 19, 1921, computed for ¼° isophanes from 43 to 90, Murray; July 31, 1921, revised from isophane 23 to 0, Hopkins; August 8, 1921, computed for ¼° isophanes from 23 to 0, Murray; September 4, 1922, revised from isophane 61 to 90, Hopkins; June 15, 1926, equivalents in centigrade added, Murray.

RULES FOR THE COMPUTATION OF CONSTANTS

1. Beginning with the base isophanes 43 and thermal means *a* 55.00, *w* 76.00, and *c* 34.00, the rates are subtracted poleward and added equatorward, added to minus poleward for each 1° isophane, and approximately one-fourth of the rate for each 0.25 degree isophane.
2. Beginning with isophane 90, the rates are subtracted from the minus, and added to the plus means equatorward to isophane 0.
3. Beginning with isophane 0, the rates are subtracted from the plus, and added to the minus means poleward to isophane 90.
4. The constants are computed for degrees Fahrenheit by the given Fahrenheit rates.

In the computation for 0.25 degree isophanes, fractions above 0.01 are adjusted to even hundredths by accumulation, or by alternating lower and higher rates, which may involve a slight range of error but of little or no consequence in application.

EXPLANATION OF TABLE 3

The purpose of this table is to supplement table 2 in providing modified requirement constants of the bioclimatic law in degrees Fahrenheit and degrees Centigrade to more nearly correspond to the relative modification in effects of temperature on bioclimatic phenomena with higher and lower isophanes and altitudes. The thermal constants are for *a* the annual mean, *w* mean of the warmest, and *c* mean of the coldest months, with a scale of zonal constants as characterized by ranges in sea-level isophanes and their corresponding ranges in *a*, *w*, and *c* thermal constants.

EXAMPLES OF APPLICATION

Part 1: Examples 8, 17, 18, 22, 24, 26, 34; figs. 16, 19, 20, 21, 22; thermal record cards A and C.

Part 2: Examples 45, 46, 50, 51, 54, 55, 56, 59, 71, 72, 73, 75, 76; figure 44.

TABLE 4.—*Thermal mean constants for application in the interpretation of zonal types and analyzing type elements of geographic positions*

Zones Ma	Zones Mi	Isop.	d	e	f	h	i
I		84.00	13.17	46.70	58.82	−39.05	−19.05
	+2	83.75	13.51	46.95	59.13	−38.61	−18.61
		83.50	13.86	47.20	59.44	−38.17	−18.17
		83.25	14.20	47.45	59.75	−37.73	−17.73
		83.00	14.54	47.70	60.06	−37.30	−17.30
		82.75	14.88	47.95	60.37	−36.86	−16.86
		82.50	15.23	48.20	60.68	−36.42	−16.42
	+.2	82.25	15.57	48.45	60.99	−35.98	−15.98
		82.00	15.92	48.70	61.30	−35.55	−15.55
		81.75	16.26	48.95	61.61	−35.11	−15.11
		81.50	16.60	49.20	61.92	−34.67	−14.67
		81.25	16.94	49.45	62.23	−34.23	−14.23
		81.00	17.29	49.70	62.54	−33.80	−13.80
		80.75	17.64	49.95	62.85	−33.36	−13.36
		80.50	17.98	50.20	63.16	−32.92	−12.92
		80.25	18.32	50.45	63.47	−32.48	−12.48
	.2	80.00	18.67	50.70	63.78	−32.05	−12.05
		79.75	19.01	50.95	64.09	−31.61	−11.61
		79.50	19.35	51.20	64.40	−31.17	−11.17
		79.25	19.69	51.45	64.71	−30.73	−10.73
		79.00	20.04	51.70	65.02	−30.30	−10.30
		78.75	20.39	51.95	65.33	−29.86	−9.86
		78.50	20.73	52.20	65.64	−29.42	−9.42
		78.25	21.07	52.45	65.95	−28.98	−8.98
		78.00	21.42	52.70	66.26	−28.55	−8.55
		77.75	21.76	52.95	66.57	−28.11	−8.11
	−.2	77.50	22.10	53.20	66.88	−27.67	−7.67
		77.25	22.44	53.45	67.19	−27.23	−7.23
		77.00	22.79	53.70	67.50	−26.80	−6.80
		76.75	23.14	53.95	67.81	−26.36	−6.36
		76.50	23.48	54.20	68.12	−25.92	−5.92
		76.25	23.82	54.45	68.43	−25.48	−5.48
		76.00	24.17	54.70	68.74	−25.05	−5.05
	−2	75.75	24.51	54.95	69.05	−24.61	−4.61
		75.50	24.85	55.20	69.36	−24.17	−4.17
		75.25	25.19	55.45	69.67	−23.73	−3.73
		75.00	25.54	55.70	69.98	−23.30	−3.30
		74.75	25.89	55.95	70.29	−22.86	−2.86
		74.50	26.23	56.20	70.60	−22.42	−2.42
	+3	74.25	26.57	56.45	70.91	−21.98	−1.98
		74.00	26.92	56.70	71.22	−21.55	−1.55
		73.75	27.26	56.95	71.53	−21.11	−1.11
		73.50	27.60	57.20	71.84	−20.67	−.67
		73.25	27.94	57.45	72.15	−20.23	−.23
	+.3	73.00	28.29	57.70	72.46	−19.80	+.20
		72.75	28.64	57.95	72.77	−19.36	+.64
		72.50	28.98	58.20	73.08	−18.92	+1.08
I		72.25	29.32	58.45	73.39	−18.48	1.52
		72.00	29.67	58.70	73.70	−18.05	1.95
		71.75	30.01	58.95	74.01	−17.60	2.36
		71.50	30.35	59.20	74.32	−17.16	2.84
		71.25	30.69	59.45	74.63	−16.72	3.28
		71.00	31.04	59.70	74.94	−16.30	3.70
	.3	70.75	31.39	59.95	75.25	−15.86	4.13
		70.50	31.73	60.20	75.56	−15.42	4.57
		70.25	32.07	60.45	75.87	−14.98	5.01
		70.00	32.42	60.70	76.18	−14.55	5.45
		69.75	32.74	60.95	76.49	−14.17	5.82
		69.50	33.05	61.20	76.80	−13.80	6.20
		69.25	33.36	61.45	77.11	−13.42	6.57
		69.00	33.67	61.70	77.42	−13.05	6.95
		68.75	33.99	61.95	77.73	−12.67	7.32
	−.3	68.50	34.30	62.20	78.04	−12.30	7.70
		68.25	34.61	62.45	78.35	−11.92	8.07
		68.00	34.92	62.70	78.66	−11.55	8.45
		67.75	35.24	62.95	78.97	−11.17	8.82
		67.50	35.55	63.20	79.28	−10.80	9.20
		67.25	35.86	63.45	79.59	−10.42	9.57
	−3	67.00	36.17	63.70	79.90	−10.05	9.95
		66.75	36.49	63.95	80.21	−9.67	10.32
		66.50	36.80	64.20	80.52	−9.30	10.70
		66.25	37.11	64.45	80.83	−8.92	11.07
	+4	66.00	37.42	64.70	81.14	−8.55	11.45
		65.75	37.74	64.95	81.45	−8.17	11.82
		65.50	38.05	65.20	81.76	−7.80	12.20
	+.4	65.25	38.36	65.45	82.07	−7.42	12.57
		65.00	38.67	65.70	82.38	−7.05	12.95
		64.75	38.99	65.95	82.69	−6.67	13.32
		64.50	39.30	66.20	83.00	−6.30	13.70
		64.25	39.61	66.45	83.31	−5.92	14.07
		64.00	39.92	66.70	83.62	−5.55	14.45
		63.75	40.24	66.95	83.93	−5.17	14.82
		63.50	40.55	67.20	84.24	−4.80	15.20
	.4	63.25	40.86	67.45	84.55	−4.42	15.57
		63.00	41.17	67.70	84.86	−4.05	15.95
		62.75	41.49	67.95	85.17	−3.67	16.32
		62.50	41.80	68.20	85.48	−3.30	16.70
		62.25	42.11	68.45	85.79	−2.92	17.07
		62.00	42.42	68.70	86.10	−2.55	17.45
		61.75	42.74	68.95	86.41	−2.17	17.82
	−.4	61.50	43.05	69.20	86.72	−1.80	18.20
		61.25	43.36	69.45	87.03	−1.42	18.57
		61.00	43.67	69.70	87.34	−1.05	18.95

Table 4.—*Thermal mean constants for application in the interpretation of zonal types and analyzing type elements of geographic positions*—Continued

Zones Ma	Zones Mi	Isop.	d	e	f	h	i
I		60.75	43.99	69.95	87.65	−.67	19.32
	−4	60.50	44.30	70.20	87.96	−.30	19.70
		60.25	44.61	70.45	88.27	+.08	20.07
		60.00	44.92	70.70	88.58	+.45	20.45
II		59.75	45.24	70.95	88.89	+.82	20.82
	+1	59.50	45.55	71.20	89.20	1.20	21.20
		59.25	45.86	71.45	89.51	1.57	21.57
	+.1	59.00	46.17	71.70	89.82	1.95	21.95
		58.75	46.49	71.95	90.13	2.32	22.32
		58.50	46.80	72.20	90.44	2.70	22.70
	.1	58.25	47.11	72.45	90.75	3.07	23.07
		58.00	47.42	72.70	91.06	3.45	23.45
		57.75	47.74	72.95	91.37	3.82	23.82
	−.1	57.50	48.05	73.20	91.68	4.20	24.20
		57.25	48.36	73.45	91.99	4.57	24.57
	−1	57.00	48.67	73.70	92.30	4.95	24.95
		56.75	48.99	73.95	92.60	5.32	25.32
	+2	56.50	49.30	74.20	92.90	5.70	25.70
		56.25	49.61	74.45	93.20	6.07	26.07
		56.00	49.92	74.70	93.50	6.45	26.45
		55.75	50.24	74.95	93.80	6.82	26.82
	+.2	55.50	50.55	75.20	94.10	7.20	27.20
		55.25	50.86	75.45	94.40	7.57	27.57
		55.00	51.17	75.70	94.70	7.95	27.95
		54.75	51.49	75.95	95.00	8.32	28.32
		54.50	51.80	76.20	95.30	8.70	28.70
		54.25	52.11	76.45	96.50	9.07	29.07
		54.00	52.42	76.70	95.90	9.45	29.45
	.2	53.75	52.74	76.95	96.20	9.82	29.82
		53.50	53.05	77.20	96.50	10.20	30.20
		53.25	53.36	77.45	96.80	10.57	30.57
		53.00	53.67	77.70	97.10	10.95	30.95
		52.75	53.99	77.95	97.40	11.32	31.32
		52.50	54.30	78.20	97.70	11.70	31.70
	−.2	52.25	54.61	78.45	98.00	12.07	32.07
		52.00	54.92	78.70	98.30	12.45	32.45
		51.75	55.24	78.95	98.60	12.82	32.82
		51.50	55.55	79.20	98.90	13.20	33.20
	−2	51.25	55.86	79.45	99.20	13.57	33.57
		51.00	56.17	79.70	99.50	13.95	33.95
		50.75	56.49	79.95	99.75	14.32	34.32
	+3	50.50	56.80	80.20	100.00	14.70	34.70
		50.25	57.11	80.45	100.25	15.07	35.07
	+.3	50.00	57.42	80.70	100.50	15.45	35.45
		49.75	57.73	80.95	100.75	15.82	35.82
		49.50	58.05	81.20	101.00	16.20	36.20
	.3	49.25	58.36	81.45	101.25	16.57	36.57
		49.00	58.67	81.70	101.50	16.95	36.95
		48.75	58.98	81.95	101.75	17.32	37.32
	−.3	48.50	59.29	82.20	102.00	17.70	37.70
		48.25	59.61	82.45	102.25	18.07	38.07
	−3	48.00	59.92	82.70	102.50	18.45	38.45
		47.75	60.23	82.95	102.75	18.82	38.82
	+4	47.50	60.54	83.20	103.00	19.20	39.20
		47.25	60.85	83.45	103.25	19.57	39.57
		47.00	61.17	83.70	103.50	19.95	39.95
	+.4	46.75	61.49	83.95	103.75	20.32	40.32
		46.50	61.80	84.20	104.00	20.70	40.70
		46.25	62.11	84.45	104.25	21.07	41.07
		46.00	62.42	84.70	104.50	21.45	41.45
		45.75	62.74	84.95	104.75	21.82	41.82
	.4	45.50	63.05	85.20	105.00	22.20	42.20
		45.25	63.36	85.45	105.25	22.57	42.57
		45.00	63.67	85.70	105.50	22.95	42.95
		44.75	63.98	85.95	105.75	23.32	43.32
		44.50	64.30	86.20	106.00	23.70	43.70
		44.25	64.61	86.45	106.25	24.07	44.07
	−.4	44.00	64.92	86.70	106.50	24.45	44.45
		43.75	65.23	86.95	106.75	24.82	44.82
		43.50	65.54	87.20	107.00	25.20	45.20
	−4	43.25	65.85	87.45	107.25	25.57	45.57
		43.00	66.17	87.70	107.50	25.95	45.95
		42.75	66.48	87.95	107.75	26.32	46.32
	+5	42.50	66.79	88.20	108.00	26.70	46.70
		42.25	67.10	88.45	108.25	27.07	47.07
	+.5	42.00	67.42	88.70	108.50	27.45	47.45
		41.75	67.73	88.95	108.75	27.82	47.82
		41.50	68.04	89.20	109.00	28.20	48.20
	.5	41.25	68.35	89.45	109.25	28.57	48.57
		41.00	68.66	89.70	109.50	28.95	48.95
		40.75	68.96	89.92	109.72	29.32	49.32
	−.5	40.50	69.26	90.15	109.95	29.70	49.70
		40.25	69.56	90.37	110.17	30.07	50.07
	−5	40.00	69.86	90.60	110.40	30.45	50.45
		39.75	70.16	90.82	110.62	30.82	50.82
		39.50	70.46	91.05	110.85	31.20	51.20
	+6	39.25	70.76	91.27	111.07	31.57	51.57
		39.00	71.06	91.50	111.30	31.95	51.95
		38.75	71.36	91.72	111.52	32.32	52.32
	+.6	38.50	71.66	91.95	111.75	32.70	52.70
		38.25	71.96	92.17	111.97	33.07	53.07
		38.00	72.26	92.40	112.20	33.45	53.45
		37.75	72.54	92.60	112.40	33.82	53.82
		37.50	72.83	92.80	112.60	34.20	54.20
		37.25	73.12	93.00	112.80	34.57	54.57
		37.00	73.41	93.20	113.60	34.95	54.95
	.6	36.75	73.69	93.40	113.20	35.32	55.32
		36.50	73.98	93.60	113.40	35.70	55.70
		36.25	74.27	93.80	113.60	36.07	56.07
		36.00	74.56	94.00	113.80	36.45	56.45
		35.75	74.84	94.20	114.00	36.82	56.82
		35.50	75.13	94.40	114.20	37.20	57.20
	−.6	35.25	75.42	94.60	114.40	37.57	57.57
		35.00	75.71	94.80	114.60	37.95	57.95
II		34.75	75.99	95.00	114.80	38.32	58.32
	−6	34.50	76.28	95.20	115.00	38.70	58.70
		34.25	76.57	95.40	115.20	39.06	59.06
		34.00	76.86	95.60	115.40	39.45	59.45
		33.75	77.14	95.80	115.60	39.82	59.82
	+7	33.50	77.43	96.00	115.80	40.20	60.20
		33.25	77.72	96.20	116.00	40.57	60.57
		33.00	78.01	96.40	116.20	40.95	60.95
	+.7	32.75	78.26	96.52	116.32	41.32	61.32
		32.50	78.51	96.65	116.45	41.70	61.70
		32.25	78.76	96.77	116.57	42.07	62.07
		32.00	79.01	96.90	116.70	42.45	62.45
	.7	31.75	79.26	97.02	116.82	42.82	62.82
		31.50	79.51	97.15	116.95	43.20	63.20
		31.25	79.75	97.27	117.07	43.57	63.57
	−.7	31.00	80.01	97.40	117.20	43.95	63.95
		30.75	80.26	97.52	117.32	44.32	64.32
		30.50	80.51	97.65	117.45	44.70	64.70
	−7	30.25	80.76	97.77	117.57	45.07	65.07
		30.00	81.01	97.90	117.70	45.45	65.45
III		29.75	81.26	98.02	117.82	45.82	65.82
		29.50	81.51	98.15	117.95	46.20	66.20
	+1	29.25	81.76	98.27	118.07	46.57	66.57
		29.00	82.01	98.40	118.20	46.95	66.95
		28.75	82.26	98.52	118.32	47.32	67.32
		28.50	82.51	98.65	118.45	47.70	67.70
	+.1	28.25	82.76	98.77	118.57	48.07	68.07
		28.00	83.01	98.90	118.70	48.45	68.45
		27.75	83.26	99.02	118.82	48.82	68.82
		27.50	83.51	99.15	118.95	49.20	69.20
		27.25	83.76	99.27	119.07	49.57	69.57
	.1	27.00	84.01	99.40	119.20	49.95	69.95
		26.75	84.23	99.47	119.27	50.32	70.32
		26.50	84.46	99.55	119.35	50.70	70.70
		26.25	84.68	99.62	119.42	51.07	71.07
		26.00	84.91	99.70	119.50	51.45	71.45
		25.75	85.12	99.77	119.57	51.82	71.82
	−.1	25.50	85.34	99.85	119.65	52.20	72.20
		25.25	85.57	99.92	119.72	52.57	72.57
		25.00	85.81	100.00	119.80	52.95	72.95
		24.75	86.00	100.07	119.87	53.27	73.27
	−1	24.50	86.20	100.15	119.95	53.60	73.60
		24.25	86.40	100.22	120.02	53.92	73.92
		24.00	86.61	100.30	120.10	54.25	74.25
		23.75	86.81	100.37	120.17	54.57	74.57
		23.50	87.01	100.45	120.25	54.90	74.90
	+2	23.25	87.21	100.52	120.32	55.22	75.22
		23.00	87.41	100.60	120.40	55.55	75.55
		22.75	87.61	100.67	120.47	55.87	75.87
		22.50	87.81	100.75	120.55	56.20	76.20
		22.25	88.01	100.82	120.62	56.52	76.52
		22.00	88.21	100.90	120.70	56.85	76.85
	+.2	21.75	88.41	100.97	120.77	57.17	77.17
		21.50	88.61	101.05	120.85	57.50	77.50
		21.25	88.81	101.12	120.92	57.82	77.82
		21.00	89.01	101.20	121.00	58.15	78.15
		20.75	89.21	101.27	121.07	58.47	78.47
		20.50	89.41	101.35	121.15	58.80	78.80
		20.25	89.61	101.42	121.22	59.12	79.12
		20.00	89.81	101.50	121.30	59.45	79.45
		19.75	90.01	101.57	121.37	59.77	79.77
	.2	19.50	90.21	101.65	121.45	60.10	80.10
		19.25	90.41	101.72	121.52	60.42	80.42
		19.00	90.61	101.80	121.60	60.75	80.75
		18.75	90.81	101.87	121.67	61.07	81.07
		18.50	91.01	101.95	121.75	61.40	81.40
		18.25	91.21	102.02	121.82	61.72	81.72
		18.00	91.41	102.10	121.90	62.05	82.05
		17.75	91.61	102.17	121.97	62.37	82.37
		17.50	91.81	102.25	122.05	62.70	82.70
	−.2	17.25	92.01	102.32	122.12	63.02	83.02
		17.00	92.21	102.40	122.20	63.35	83.35
		16.75	92.41	102.47	122.27	63.67	83.67
		16.50	92.61	102.55	122.35	64.00	84.00
		16.25	92.81	102.62	122.42	64.32	84.32
		16.00	93.01	102.70	122.50	64.65	84.65
	−2	15.75	93.21	102.77	122.57	64.97	84.97
		15.50	93.41	102.85	122.65	65.30	85.30
		15.25	93.61	102.92	122.72	65.62	85.62
		15.00	93.81	103.00	122.80	65.95	85.95
		14.75	94.01	103.07	122.87	66.27	86.27
		14.50	94.21	103.15	122.95	66.60	86.60
		14.25	94.41	103.22	123.02	66.92	86.92
		14.00	94.61	103.30	123.10	67.25	87.25
	+3	13.75	94.81	103.37	123.17	67.57	87.57
		13.50	95.01	103.45	123.25	67.90	87.90
		13.25	95.21	103.52	123.32	68.22	88.22
		13.00	95.41	103.60	123.40	68.55	88.55
		12.75	95.61	103.67	123.47	68.87	88.87
		12.50	95.81	103.75	123.55	69.20	89.20
		12.25	96.01	103.82	123.62	69.52	89.52
		12.00	96.21	103.90	123.70	69.85	89.85
		11.75	96.41	103.97	123.77	70.17	90.17
		11.50	96.61	104.05	123.85	70.50	90.50
	+.3	11.25	96.81	104.12	123.92	70.82	90.82
		11.00	97.01	104.20	124.00	71.15	91.15
		10.75	97.21	104.27	124.07	71.47	91.47
		10.50	97.41	104.35	124.15	71.80	91.80
		10.25	97.61	104.42	124.22	72.12	92.12
		10.00	97.81	104.50	124.30	72.45	92.45
		9.75	98.01	104.57	124.37	72.77	92.77
	.3	9.50	98.21	104.65	124.45	73.10	93.10
		9.25	98.41	104.72	124.52	73.42	93.42
		9.00	98.61	104.80	124.60	73.75	93.75

TABLE 4.—*Thermal mean constants for application in the interpretation of zonal types and analyzing type elements of geographic positions*—Continued

Zones Ma	Zones Mi	*Isop.*	*d*	*e*	*f*	*h*	*i*
III		8.75	98.81	104.87	124.67	74.07	94.07
	.3	8.50	99.01	104.95	124.75	74.40	94.40
		8.25	99.21	105.02	124.82	74.72	94.72
		8.00	99.41	105.10	124 92	75.05	95.05
		7.75	99.61	105.17	124.97	75.37	95.37
		7.50	99.81	105.25	125.05	75.70	95.70
		7.25	100.01	105.32	125.12	76.02	96.02
	−.3	7.00	100.21	105.40	125.20	76.35	96.35
		6.75	100.41	105.47	125.27	76.67	96.67
		6.50	100.61	105.55	125.35	77.00	97.00
		6.25	100.81	105.62	125.42	77.32	97.32
		6.00	101.01	105.70	125.50	77.65	97.65
		5.75	101.21	105.77	125.57	77.97	97.97
	−3	5.50	101.41	105.85	125.65	78.30	98.30
		5.25	101.61	105.92	125.73	78.62	98.62
		5.00	101.81	106.00	125.80	78.95	98.95
		4.75	102.01	106.07	125.87	79.27	99.27
	+4	4.50	102.21	106.15	125.95	79.60	99.60
		4.25	102.41	106.22	126.02	79.92	99.92
III		4.00	102.61	106.30	126.10	80.25	100.25
	+.4	3.75	102.81	106.37	126.17	80.57	100.57
		3.50	103.01	106.45	126.25	80.90	100.90
		3.25	103.21	106.52	•126.32	81.22	101.22
		3.00	103.41	106.60	126.40	81.55	101.55
		2.75	103.61	106.67	126.47	81.87	101.87
	.4	2.50	103.81	160.75	126.55	82.20	102.20
		2.25	104.01	106.82	126.62	82.55	102.55
		2.00	104.21	106.90	126.70	82.85	102.85
		1.75	104.41	106.97	126.77	83.17	103.17
		1.50	104.61	107.05	126.85	83.50	103.50
		1.25	104.81	107.12	126.92	83.82	103.82
	−.4	1.00	105.01	107.20	127.00	84.15	104.15
		.75	105.21	107.27	127.07	84.47	104.47
		.50	105.41	107.35	127.15	84.80	104.80
	−4	.25	105.61	107.42	127.22	85.12	105.12
		.00	105.81	107.50	127.30	85.45	105.45

Schedule of modified unit constant rates in degrees Fahrenheit for 1° isophanes

d Isophanes	*d* Rate	*e* Isophanes	*e* Rate	*f* Isophanes	*f* Rato	*h–i* Isophanes	*h–i* Rate
84.00–70.00	1.375	84.00–41.00	1.00	84.00–57.00	1.24	84.00–70.00	1.75
70.00–42.00	1.25	41.00–38.00	.90	57.00–51.00	1.20	70.00–25.00	1.50
42.00–41.00	1.24	38.00–33.00	.80	51.00–41.00	1.00	25.00– .00	1.30
41.00–38.00	1.20	33.00–27.00	.50	41.00–38.00	.90	84.00– .00	1.48+
38.00–33.00	1.15	27.00– .00	.30	38.00–33.00	.80		
33.00–27.00	1.00	84.00– .00	.72+	33.00–27.00	.50		
27.00–25.00	.90			27.00– .00	.30		
25.00– .00	.80			84.00– .00	.81+		
84.00– .00	1.10+						

d Mean maximum temperature for the year.
e Mean maximum temperature for the warmest month.
f Highest recorded temperature, or absolute maximum.
h Mean minimum temperature for the coldest month.
i Mean minimum temperature for the year.

EXPLANATION OF TABLE 4

The object of this table of modified thermal constants is to supplement table 3 by giving constants for the additional thermal elements *d* mean maximum temperature for the year, *e* mean maximum temperature for the warmest month, *f* highest recorded temperature or absolute maximum, *h* mean minimum temperature for the coldest month, and *i* mean minimum temperature for the year, as computed by the given schedule of unit constant rates from averages of the records at Parkersburg, W. Va., and Marietta, Ohio, in United States Weather Bureau Bulletin W, 1926. The principle and method of application are the same as for table 3.

EXAMPLES OF APPLICATION

Part 1: Thermal record card A.
Part 2: Examples 46, 55, 56, 71, 72, 73.

TABLE 5.—*Thermal constants for the sum of the monthly means above 43°, 40°, or 35° F., and effective periods in days*

Zones Ma	Zones Mi	*Isop.*	Sum *°F.*	Per. *Days*
I	−2	75.00	6.00	0
		74.75	6.25	2
		74.50	6.50	3
	+3	74.25	6.75	5
		74.00	7.00	7
		73.75	7.25	9
		73.50	7.50	10
		73.25	7.75	12
	+.3	73.00	8.00	14
		72.75	8.25	17
		72.50	8.50	18
		72.25	8.75	20
		72.00	9.00	22
		71.75	9.50	24
		71.50	10.00	25
		71.25	10.50	27
		71.00	11.00	29
	.3	70.75	11.50	31
		70.50	12.00	32
		70.25	12.50	34
		70.00	13.00	35
		69.75	13.50	37
		69.50	14.00	38
		69.25	14.50	40
		69.00	15.00	42
		68.75	15.50	44
	−.3	68.50	16.00	45
		68.25	16.50	47
		68.00	17.00	49
I		67.75	17.75	51
		67.50	18.50	53
	−3	67.25	19.25	55
		67.00	20.00	57
		66.75	20.75	59
		66.50	21.50	60
		66.25	22.25	62
	+4	66.00	23.00	64
		65.75	24.00	67
		65.50	25.00	68
		65.25	26.00	70
	+.4	65.00	27.00	72
		64.75	28.00	74
		64.50	29.00	75
		64.25	30.00	77
		64.00	31.00	79
		63.75	32.00	81
		63.50	33.00	82
	.4	63.25	34.00	84
		63.00	35.00	86
		62.75	36.00	88
		62.50	37.00	89
		62.25	38.00	91
		62.00	39.00	93
		61.75	40.00	95
	−.4	61.50	41.00	96
		61.25	42.00	98
		61.00	43.00	100
I		60.75	44.00	102
		60.50	45.00	103
	−4	60.25	46.00	105
		60.00	47.00	107
II		59.75	48.00	109
	+1	59.50	49.00	110
		59.25	50.00	112
	+.1	59.00	51.00	114
		58.75	52.00	116
		58.50	53.00	117
	.1	58.25	54.00	119
		58.00	55.00	121
		57.75	56.00	124
	−.1	57.50	57.00	127
		57.25	58.00	128
	−1	57.00	59.00	130
		56.75	60.00	132
		56.50	61.00	134
	+2	56.25	62.00	137
		56.00	63.00	139
		55.75	64.50	141
		55.50	66.00	143
	+.2	55.25	67.50	145
		55.00	69.00	147
		54.75	70.50	149
		54.50	72.00	150
	.2	54.25	73.50	152
		54.00	75.00	154
		53.75	77.00	156

TABLE 5.—*Thermal constants for the sum of the monthly means above 43°, 40°, or 35° F., and effective periods in days*—Continued

Zones		Isop.	Sum	Per.	Zones		Isop.	Sum	Per.	Zones		Isop.	Sum	Per.
Ma	*Mi*		*°F.*	*Days*	*Ma*	*Mi*		*°F.*	*Days*	*Ma*	*Mi*		*°F.*	*Days*
II		53.50	79.00	158	II		35.75	252.00	299	III		17.75	468.00	365
	.2	53.25	81.00	160		−.6	35.50	255.00	301			17.50	471.00	365
		53.00	83.00	162			35.25	258.00	303		−.2	17.25	474.00	365
		52.75	85.00	164			35.00	261.00	305			17.00	477.00	365
	−.2	52.50	87.00	166			34.75	264.00	307			16.75	480.00	365
		52.25	89.00	168		−6	34.50	267.00	308			16.50	483.00	365
		52.00	91.00	170			34.25	270.00	310			16.25	486.00	365
		51.75	93.00	172			34.00	273.00	312			16.00	489.00	365
	−2	51.50	95.00	174			33.75	276.00	314			15.75	492.00	365
		51.25	97.00	176		+7	33.50	279.00	316		−2	15.50	495.00	365
		51.00	99.00	178			33.25	282.00	318			15.25	498.00	365
	+3	50.75	101.00	181			33.00	285.00	320			15.00	501.00	365
		50.50	103.00	183		+.7	32.75	288.00	322			14.75	504.00	365
	+.3	50.25	105.00	185			32.50	291.00	324			14.50	507.00	365
		50.00	107.00	187			32.25	294.00	326			14.25	510.00	365
		49.75	109.00	189			32.00	297.00	328			14.00	513.00	365
	.3	49.50	111.00	190		.7	31.75	300.00	330			13.75	516.00	365
		49.25	113.00	192			31.50	303.00	332		+3	13.50	519.00	365
		49.00	115.00	194			31.25	306.00	334			13.25	522.00	365
	−.3	48.75	117.00	196		−.7	31.00	309.00	336			13.00	525.00	365
		48.50	119.00	198			30.75	312.00	338			12.75	528.00	365
	−3	48.25	121.00	200			30.50	315.00	339			12.50	531.00	365
		48.00	123.00	202		−7	30.25	318.00	341			12.25	534.00	365
		47.75	125.00	204			30.00	321.00	343			12.00	537.00	365
	+4	47.50	127.00	206	III		29.75	324.00	345			11.75	540.00	365
		47.25	129.00	208		+1	29.50	327.00	347			11.50	543.00	365
		47.00	131.00	210			29.25	330.00	349		+.3	11.25	546.00	365
	+.4	46.75	133.50	212			29.00	333.00	351			11.00	549.00	365
		46.50	136.00	214			28.75	336.00	353			10.75	552.00	365
		46.25	138.50	216			28.50	339.00	354			10.50	555.00	365
		46.00	141.00	218		+.1	28.25	342.00	356			10.25	558.00	365
		45.75	143.50	220			28.00	345.00	358			10.00	561.00	365
	.4	45.50	146.00	222			27.75	348.00	360			9.75	564.00	365
		45.25	148.50	224			27.50	351.00	362			9.50	567.00	365
		45.00	151.00	226			27.25	354.00	364			9.25	570.00	365
		44.75	153.50	228		.1	27.00	357.00	365		.3	9.00	573.00	365
		44.50	156.00	230			26.75	360.00	365			8.75	576.00	365
		44.25	158.50	232			26.50	363.00	365			8.50	579.00	365
	−.4	44.00	161.00	234			26.25	366.00	365			8.25	582.00	365
		43.75	163.50	236			26.00	369.00	365			8.00	585.00	365
		43.50	166.00	238			25.75	372.00	365			7.75	588.00	365
	−4	43.25	168.50	240			25.50	375.00	365			7.50	591.00	365
		43.00	171.00	242		−.1	25.25	378.00	365			7.25	594.00	365
	+5	42.75	173.50	244			25.00	381.00	365		−.3	7.00	597.00	365
		42.50	176.00	245			24.75	384.00	365			6.75	600.00	365
	+.5	42.25	178.50	247			24.50	387.00	365			6.50	603.00	365
		42.00	181.00	249		−1	24.25	390.00	365			6.25	606.00	365
		41.75	183.50	251			24.00	393.00	365			6.00	609.00	365
	.5	41.50	186.00	253			23.75	396.00	365			5.75	612.00	365
		41.25	188.50	255			23.50	399.00	365		−3	5.50	615.00	365
		41.00	191.00	257			23.25	402.00	365			5.25	618.00	365
	−.5	40.75	193.50	259		+2	23.00	405.00	365			5.00	621.00	365
		40.50	196.00	261			22.75	408.00	365			4.75	624.00	365
	−5	40.25	198.50	263			22.50	411.00	365		+4	4.50	627.00	365
		40.00	201.00	265			22.25	414.00	365			4.25	630.00	365
		39.75	204.00	267			22.00	417.00	365			4.00	633.00	365
	+6	39.50	207.00	269			21.75	420.00	365		+.4	3.75	636.00	365
		39.25	210.00	271		+.2	21.50	423.00	365			3.50	639.00	365
		39.00	213.00	273			21.25	426.00	365			3.25	642.00	365
		38.75	216.00	275			21.00	429.00	365			3.00	645.00	365
	+.6	38.50	219.00	277			20.75	432.00	365			2.75	648.00	365
		38.25	222.00	279			20.50	435.00	365			2.50	651.00	365
		38.00	225.00	281			20.25	438.00	365		.4	2.25	654.00	365
		37.75	228.00	283			20.00	441.00	365			2.00	657.00	365
		37.50	231.00	285			19.75	445.00	365			1.75	660.00	365
		37.25	234.00	287			19.50	448.00	365			1.50	663.00	365
	.6	37.00	237.00	289		.2	19.25	451.00	365			1.25	666.00	365
		36.75	240.00	291			19.00	453.00	365		−.4	1.00	669.00	365
		36.50	243.00	293			18.75	456.00	365			.75	672.00	365
		36.25	246.00	295			18.50	459.00	365			.50	675.00	365
		36.00	249.00	297			18.25	462.00	365		−4	.25	678.00	365
							18.00	465.00	365			.00	681.00	365

Schedule of modified unit constant rates in degrees Fahrenheit and days for 1° isophanes

Degrees Fahrenheit		Days			
Isophanes	Rate	Isophanes	Rate	Isophanes	Rate
75.00–72.00	1.00	75.00–73.00	7	51.00–50.00	9
72.00–68.00	2.00	73.00–72.00	8	50.00–49.00	7
68.00–66.00	3.00	72.00–71.00	7	49.00–43.00	8
66.00–56.00	4.00	71.00–70.00	6	43.00–42.00	7
56.00–54.00	6.00	70.00–68.00	7	42.00–35.00	8
54.00–47.00	8.00	68.00–67.00	8	35.00–34.00	7
47.00–40.00	10.00	67.00–66.00	7	34.00–33.00	8
40.00– 0.00	12.00	66.00–65.00	8	33.00–32.00	8
75.00– 0.00	9.00	65.00–58.00	7	32.00–30.00	7
		58.00–56.00	9	30.00–29.00	8
		56.00–55.00	8	29.00–27.00	7
		55.00–54.00	7	27.00– 0.00	0
		54.00–51.00	8	75.00–27.00	7.6+
				75.00– 0.00	4.8+

EXPLANATION OF TABLE 5

The purpose of this table is to give constants for the so-called effective sum of the monthly mean temperatures above given standard monthly mean zero units or sum indices for the warmer period of the year, together with equivalent effective period constants in days and the corresponding major and minor zonal constants for sea-level isophanes ranging from 75 poleward to 0 equatorward for the northern and southern continents.

Under zones and isophanes is given the standard sea-level scale of 0.25° isophanes and corresponding major and minor zonal (and minor zonal sectional) constants. *Sum Deg. F.* gives the sum constants in degrees Fahrenheit as computed from the required sum indices, as index 43° F. for isophanes 0 to 57, 40° F. for isophanes 57 to 60, and 35° F. for isophanes 60 to 75; each represents the corresponding effective influence in which the sum index of 35° for isophanes above 60 is assumed to be equivalent to that of 43° for isophanes below 57, thus providing for an increase in effective influence on life activities with higher isophanes, latitudes, and altitudes. *Per. Days* gives the periods in day constants of effective temperature to correspond with the sum constants for each 0.25° isophane.

The schedule of modified unit constant rates gives under Degrees Fahrenheit the rate in degrees Fahrenheit per 1° isophane for given ranges in isophanes, by which the sum constants are computed from the sum record 156° F. at the intercontinental base, equivalent isophane 44.50, with a record period of 230 days. It will be noted that the rates in degrees Fahrenheit decrease from 12 for isophane 0, or 0 to 40, to 1 for isophane 75, or 72 to 75, with an average rate of 9° from isophane 0 to 75, giving a range in sums from 681° for isophane 0 to 6° for isophane 75; while the corresponding rates in equivalent effective days range from 6 to 9 days per 1° isophane between 27 and 75, with no rate between isophanes 0 and 27 and with an average rate of 7.6+ days from isophanes 27 to 75, with a period constant of 365 days from isophanes 27 to 0.

It is to be kept in mind that in the development of the rates and in the computation of constants for this table (as for all the tables of constants) a great deal of time was required in a study of records of representative meteorological stations from the Equator poleward on different continents. Many trials were made of different average and modified rates, and many tests of application were made before the final adoption of the rates and constants.

The method of procedure to find the sum and period constants for a given record position is to find in the usual way the *ei* to the altitude of the position, which referred to the table gives the constants. Then to find the record sum and period for the same position and the *ri* and zonal types, the procedure is as shown in the examples listed.

EXAMPLES OF APPLICATION:

Part 1: Example 9; figure 17; thermal record card A.
Part 2: Examples 46, 54, 55, 56, 71, 72, 73, 75, 76, 85, 86.

TABLE 6.—*Spring and autumn date and period constants for killing frosts*

Zones *Ma*	Zones *Mi*	*Isop.*	*S*	*A*	*P*
I	+.4	64.75	205	205	0
		64.50	204	206	2
		64.25	203	207	4
		64.00	202	208	6
		63.75	201	209	8
		63.50	200	210	10
	.4	63.25	199	211	12
		63.00	198	212	14
		62.75	197	213	16
		62.50	196	214	18
		62.25	195	215	20
		62.00	194	216	22
		61.75	193	217	24
	−.4	61.50	192	218	26
		61.25	191	219	28
		61.00	190	220	30
		60.75	189	221	32
	−4	60.50	188	222	34
		60.25	187	223	36
		60.00	186	224	38
II	+1	59.75	185	225	40
		59.50	184	226	42
	+.1	59.25	183	227	44
		59.00	182	228	46
		58.75	181	229	48
		58.50	180	230	50
	.1	58.25	179	231	52
		58.00	178	232	54
	−.1	57.75	177	233	56
		57.50	176	234	58
	−1	57.25	175	235	60
		57.00	174	236	62
		56.75	173	237	64
	+2	56.50	172	238	66
		56.25	171	239	68
		56.00	170	240	70
		55.75	169	241	72
	+.2	55.50	168	242	74
		55.25	167	243	76
		55.00	166	244	78
		54.75	165	245	80
		54.50	164	246	82
		54.25	163	247	84
	.2	54.00	162	248	86
		53.75	161	249	88
		53.50	160	250	90
		53.25	159	251	92
		53.00	158	252	94
		52.75	157	253	96
	−.2	52.50	156	254	98
		52.25	154	255	101
		52.00	153	256	103

Zones *Ma*	Zones *Mi*	*Isop.*	*S*	*A*	*P*
II		51.75	152	257	105
	−2	51.50	151	258	107
		51.25	149	259	110
		51.00	148	260	112
	+3	50.75	147	261	114
		50.50	146	262	116
	+.3	50.25	144	263	119
		50.00	143	264	121
		49.75	142	265	123
		49.50	141	266	125
	.3	49.25	139	267	128
		49.00	138	268	130
	−.3	48.75	137	269	132
		48.50	136	270	134
	−3	48.25	134	271	137
		48.00	133	272	139
		47.75	132	273	141
	+4	47.50	131	274	143
		47.25	129	275	146
		47.00	128	276	148
	+.4	46.75	127	277	150
		46.50	126	278	152
		46.25	124	279	155
		46.00	123	280	157
		45.75	122	281	159
	.4	45.50	121	282	161
		45.25	119	283	164
		45.00	118	284	166
		44.75	117	285	168
	EB	44.50	116	286	170
		44.25	114	287	173
	−.4	44.00	113	288	175
		43.75	112	289	177
		43.50	111	290	179
	−4	43.25	109	291	182
		43.00	108	292	184
	+5	42.75	107	293	186
		42.50	106	294	188
	+.5	42.25	104	295	191
		42.00	103	296	193
		41.75	102	297	195
		41.50	100	298	198
	.5	41.25	99	299	200
		41.00	98	300	202
	−.5	40.75	97	301	204
		40.50	96	302	206
	−5	40.25	94	303	209
		40.00	93	304	211
		39.75	92	305	213
	+6	39.50	91	306	215
		39.25	89	307	218
		39.00	88	308	220

Zones *Ma*	Zones *Mi*	*Isop.*	*S*	*A*	*P*
II		38.75	87	309	222
	+.6	38.50	86	310	224
		38.25	84	311	227
		38.00	83	312	229
		37.75	82	313	231
		37.50	81	314	233
		37.25	79	315	236
		37.00	78	316	238
	.6	36.75	77	317	240
		36.50	76	318	242
		36.25	74	319	245
		36.00	72	320	248
		35.75	70	321	251
	−.6	35.50	68	322	254
		35.25	66	323	257
		35.00	64	324	260
		34.75	62	325	263
	−6	34.50	60	326	266
		34.25	58	327	269
		34.00	56	328	272
		33.75	54	329	275
	+7	33.50	52	330	278
		33.25	50	331	281
		33.00	48	332	284
	+.7	32.75	46	333	287
		32.50	44	334	290
		32.25	42	335	293
		32.00	40	336	296
	.7	31.75	38	337	299
		31.50	36	338	302
		31.25	34	339	305
	−.7	31.00	32	340	308
		30.75	30	341	311
		30.50	28	342	314
	−7	30.25	26	343	317
		30.00	24	344	320
III		29.75	22	345	323
	+1	29.50	20	347	327
		29.25	18	348	330
		29.00	16	349	333
		28.75	14	351	337
	+.1	28.50	12	353	341
		28.25	10	355	345
		28.00	8	357	349
		27.75	6	359	353
	.1	27.50	4	361	357
		27.25	2	363	361
		27.00	0	365	365

Schedule of modified unit constant rates in days for 1° isophanes

Latest in spring: Isophanes	Rate for— 1°	Rate for— 0.25°
64.75–53.00	4	1
53.00–37.00	5	3–1 1–2
37.00–36.00	6	2–1 2–2
36.00–27.00	8	2
64.75–27.00	[1] 5.44	----------

Earliest in autumn: Isophanes	Rate for— 1°	Rate for— 0.25°
64.75–30.00	4	1
30.00–29.00	5	3–1 1–2
29.00–27.00	8	2
64.75–27.00	[1] 4.2+	----------

Frostless period: Isophanes	Rate for— 1°	Rate for— 0.25°
64.75–53.00	8	2
53.00–37.00	9	3–2 1–3
37.00–36.00	10	2–2 2–3
36.00–30.00	12	3
30.00–29.00	13	3–3 1–4
29.00–27.00	16	4
64.75–27.00	[1] 9.6+	----------

[1] Average.

EXPLANATION OF TABLE 6

The object of this table is to provide requirement constants for the average year-dates of spring and autumn killing frosts, and for the frostless period in days for sea-level isophanes 64.75 to 27 of the Northern Hemisphere.

The modified rates in days for the 1° and 0.25° isophanes by which the date and period constants are computed are given in the schedule of rates as from isophanes 53 to 37 with an average rate of 5 days per 1°; 3 of the quarters are computed at the rate of 1 day per quarter and one-quarter at the rate of 2 days, and so on to avoid the use of fractions of a day. The periods for each 1° or 0.25° is simply the autumn date minus the spring date so that although the rates are given there is no need to compute the period constants by them. The zonal constants are the same for the given isophanes as in the other tables. The constants of this table are applied by the same method and process as those of the other tables.

EXAMPLES OF APPLICATION

Part 1: Example 5; figure 14.
Part 2: Examples 54, 55, 56, 71, 72, 73, 85.

TABLE 7.—*Seeding and harvest date and period constants for winter wheat in major zones I and II north*

Zones *Ma*	Zones *Mi*	*Isop.*	*S*	*H*	*P*	Zones *Ma*	Zones *Mi*	*Isop.*	*S*	*H*	*P*	Zones *Ma*	Zones *Mi*	*Isop.*	*S*	*H*	*P*
		64.00	194	252	423	II		51.75	243	203	325	II		39.75	291	155	229
		63.75	195	251	421		−2	51.50	244	202	323		+6	39.50	292	154	227
		63.50	196	250	419			51.25	245	201	321			39.25	293	153	225
		63.25	197	249	417			51.00	246	200	319			39.00	294	152	223
	.4	63.00	198	248	415		+3	50.75	247	199	317			38.75	295	151	221
		62.75	199	247	413			50.50	248	198	315		+.6	38.50	296	150	219
		62.50	200	246	411		+.3	50.25	249	197	313			38.25	297	149	217
		62.25	201	245	409			50.00	250	196	311			38.00	298	148	215
		62.00	202	244	407			49.75	251	195	309			37.75	299	147	213
		61.75	203	243	405		.3	49.50	252	194	307			37.50	300	146	211
	−.4	61.50	204	242	403			49.25	253	193	305			37.25	301	145	209
		61.25	205	241	401			49.00	254	192	303			37.00	302	144	207
		61.00	206	240	399		−.3	48.75	255	191	301		.6	36.75	303	143	205
		60.75	207	239	397			48.50	256	190	299			36.50	304	142	203
	−4	60.50	208	238	395		−3	48.25	257	189	297			36.25	305	141	201
		60.25	209	237	393			48.00	258	188	295			36.00	306	140	199
		60.00	210	236	391			47.75	259	187	293			35.75	307	139	197
I	+1	59.75	211	235	389		+4	47.50	260	186	291		−.6	35.50	308	138	195
		59.50	212	234	387			47.25	261	185	289			35.25	309	137	193
	+.1	59.25	213	233	385			47.00	262	184	287			35.00	310	136	191
		59.00	214	232	383		+.4	46.75	263	183	285			34.75	311	135	189
		58.75	215	231	381			46.50	264	182	283		−6	34.50	312	134	187
	.1	58.50	216	230	379			46.25	265	181	281			34.25	313	133	185
		58.25	217	229	377			46.00	266	180	279			34.00	314	132	183
		58.00	218	228	375			45.75	267	179	277			33.75	315	131	181
	−.1	57.75	219	227	373		.4	45.50	268	178	275		+7	33.50	316	130	179
		57.50	220	226	371			45.25	269	177	273			33.25	317	129	177
	−.1	57.25	221	225	369			45.00	270	176	271			33.00	318	128	175
		57.00	222	224	367			44.75	271	175	269		+.7	32.75	319	127	173
		56.75	223	223	365		EB	44.50	272	174	267			32.50	320	126	171
	+.2	56.50	224	222	363			44.25	273	173	265			32.25	321	125	169
		56.25	225	221	361		−.4	44.00	274	172	263			32.00	322	124	167
		56.00	226	220	359			43.75	275	171	261		.7	31.75	323	123	165
		55.75	227	219	357		−4	43.50	276	170	259			31.50	324	122	163
	+.2	55.50	228	218	355			43.25	277	169	257			31.25	325	121	161
		55.25	229	217	353		SB	43.00	278	168	255		−.7	31.00	326	120	159
		55.00	230	216	351		+5	42.75	279	167	253			30.75	327	119	157
		54.75	231	215	349			42.50	280	166	251			30.50	328	118	155
		54.50	232	214	347		+.5	42.25	281	165	249		−7	30.25	329	117	153
		54.25	233	213	345			42.00	282	164	247			30.00	330	116	151
	.2	54.00	234	212	343			41.75	283	163	245	III		29.75	331	115	149
		53.75	235	211	341		.5	41.50	284	162	243		+1	29.50	332	114	147
		53.50	236	210	339			41.25	285	161	241			29.25	333	113	145
		53.25	237	209	337			41.00	286	160	239			29.00	334	112	143
		53.00	238	208	335		−.5	40.75	287	159	237			28.75	335	111	141
		52.75	239	207	333			40.50	288	158	235		+.1	28.50	336	110	139
	−.2	52.50	240	206	331		−5	40.25	289	157	233			28.25	337	109	137
		52.25	241	205	329			40.00	290	156	231			28.00	338	108	135
		52.00	242	204	327												

The unmodified unit constant rates in days for 1° isophanes, for isophanes 64 to 28, are *S* 4 days, *H* 4 days, *P* 8 days. The rate for 0.25° is one-fourth of the 1° rate. These rates are the same for the same isophanes of the Southern Hemisphere, but seeding would begin in June equatorward to February poleward, and harvest from October equatorward to February poleward.

EXPLANATION OF TABLE 7

The object of this table is to provide intercontinental requirement constants of the average year-dates for seeding (*S*), harvest (*H*), and period (*P*) in days, of winter wheat for sea-level isophanes 64 to 28 for the Northern Hemisphere.

These constants are computed by the standard unmodified unit constant rate of 4 days to 1° isophane for seeding- and harvest-date constants, and 8 days to 1° isophane for the period constants in days between seeding and harvest dates, all from the records, *S* 272, *H* 174, *P* 267, at the Intercontinental Base (*EB*) for *ei* 44.50. The rate is subtracted from the base seeding date poleward and added equatorward; also the rate is added to the base harvest date and base period in days poleward and subtracted equatorward. The zonal constants are for the same sea-level isophanes as in the preceding tables.

EXAMPLES OF APPLICATION

Part 1: Examples 1, 3, 3*a*, 4, 19, 22, 23, 24, 27, 29; figures 12 and 13; time record cards B and Ba.
Part 2: Examples 52 and 54.

TABLE 8.—*Seeding and harvest date and period constants for spring wheat in major zones I and II north*

Zones *Ma*	*Mi*	*Isop.* 100 mer.	Year Date *S*	*H*	Days *P*	Zones *Ma*	*Mi*	*Isop.* 100 mer.	Year Date *S*	*H*	Days *P*	Zones *Ma*	*Mi*	*Isop.* 100 mer.	Year Date *S*	*H*	Days *P*
I	−.4	61.00	163	250	87	II		54.75	138	------	------	II	−.3	48.75	114	------	------
		60.75	162	------	------			54.50	137	237	100			48.50	113	225	112
	−4	60.50	161	249	88			54.25	136	------	------		−3	48.25	112	------	------
		60.25	160	------	------		.2	54.00	135	236	101			48.00	111	224	113
		60.00	159	248	89			53.75	134	------	------			47.75	110	------	------
II	+1	59.75	158	------	------			53.50	133	235	102		+4	47.50	109	223	114
		59.50	157	247	90			53.25	132	------	------			47.25	108	------	------
	+.1	59.25	156	------	------			53.00	131	234	103			47.00	107	222	115
		59.00	155	246	91			52.75	130	------	------		+.4	46.75	106	------	------
		58.75	154	------	------		−.2	52.50	129	233	104			46.50	105	221	116
	.1	58.50	153	245	92			52.25	128	------	------			46.25	104	------	------
		58.25	152	------	------			52.00	127	232	105			46.00	103	220	117
		58.00	151	244	93			51.75	126	------	------			45.75	102	------	------
	−.1	57.75	150	------	------		−2	51.50	125	231	106		.4	45.50	101	219	118
		57.50	149	243	94			51.25	124	------	------			45.25	100	------	------
	−1	57.25	148	------	------			51.00	123	230	107			45.00	99	218	119
		57.00	147	242	95		+3	50.75	122	------	------			44.75	98	------	------
		56.75	146	------	------			50.50	121	229	108			44.50	97	217	120
	+2	56.50	145	241	96		+.3	50.25	120	------	------						
		56.25	144	------	------			50.00	119	228	109						
		56.00	143	240	97			49.75	118	------	------						
		55.75	142	------	------		.3	49.50	117	227	110						
	+.2	55.50	141	239	98			49.25	116	------	------						
		55.25	140	------	------			49.00	115	226	111						
		55.00	139	238	99												

Schedule of Modified Unit Constant Rates in Days for 1° isophanes

Isophanes	Rates *S*	*H*	*P*
61.00–44.50	4	2	2

EXPLANATION OF TABLE 8

The object of this table is to provide for the Northern Hemisphere the requirement constants of the average year-dates for seeding (*S*) and harvest (*H*) dates, with periods (*P*) in days between seeding and harvest, of spring wheat for isophanes 44.50 to 61, with corresponding zonal constants, as in preceding tables.

The principle and application of these constants are the same as in table 7, except that the seeding dates are in the spring and the harvest dates in the summer or autumn.

TABLE 9.—*Phenological seasons: Year-date constants for the beginning and ending of the seasons and their stages, with warm and cold period constants*

Zones *Ma*	*Mi*	*Isop.*	Spring 1	Spring 2	Spring 3	Summer 1	Summer 2	Summer 3	Autumn 1	Autumn 2	Autumn 3	Warm Per.	Winter 1	Winter 2	Winter 3	Cold Per.
I	−2	75.00	210	------	------	------	------	------	------	------	------	0	210	210	210	365
		74.75	209	------	------	------	------	------	------	------	------	2	211	212	208	363
		74.50	208	------	------	------	------	------	------	------	------	3	211	213	206	362
	+3	74.25	207	------	------	------	------	------	------	------	------	5	212	215	205	360
		74.00	206	------	------	------	------	------	------	------	------	7	213	216	203	358
		73.75	205	------	------	------	------	------	------	------	------	9	214	217	X202	356
		73.50	204	------	------	------	------	------	------	------	------	10	214	218	199	355
		73.25	203	------	------	------	------	------	------	------	------	12	215	220	197	353
	+.3	73.00	X202	------	------	------	------	------	------	------	------	14	216	221	195	351
		72.75	200	------	------	------	------	------	------	------	------	17	217	222	194	348
		72.50	199	------	------	------	------	------	------	------	------	18	217	224	192	347
		72.25	198	------	------	------	------	------	------	------	------	20	218	225	191	345
		72.00	197	------	------	------	------	------	------	------	------	22	219	226	189	343
		71.75	196	------	------	------	------	------	------	------	------	24	220	227	187	341
		71.50	195	------	------	------	------	------	------	------	------	25	220	229	185	340
		71.25	194	------	------	------	------	------	------	------	------	27	221	231	184	338
		71.00	193	------	------	------	------	------	------	------	------	29	222	232	182	336
	.3	70.75	192	------	------	------	------	------	------	------	------	31	223	234	180	334
		70.50	191	210	------	------	------	------	------	------	210	32	223	X235	179	333
		70.25	190	209	------	------	------	------	------	------	211	34	224	237	177	331
		70.00	189	208	------	------	------	------	------	------	212	35	224	238	176	330
		69.75	188	207	------	------	------	------	------	------	213	37	225	239	174	328
		69.50	187	206	------	------	------	------	------	------	213	38	225	240	X173	327
		69.25	186	205	------	------	------	------	------	------	214	40	226	242	170	325
		69.00	185	204	------	------	------	------	------	------	215	42	227	243	168	323
		68.75	184	203	------	------	------	------	------	------	216	44	228	244	166	321
	−.3	68.50	183	X202	------	------	------	------	------	------	216	45	228	245	164	320
		68.25	182	200	------	------	------	------	------	------	217	47	229	247	163	318
		68.00	181	199	------	------	------	------	------	------	218	49	230	248	161	316
		67.75	180	198	------	------	------	------	------	------	219	51	231	250	160	314
		67.50	179	197	------	------	------	------	------	------	219	53	232	251	158	312
	−3	67.25	178	196	------	------	------	------	------	------	220	55	233	252	156	310
		67.00	177	195	------	------	------	------	------	------	221	57	234	253	154	308
		66.75	176	194	------	------	------	------	------	------	222	59	X235	255	153	306
		66.50	175	193	------	------	------	------	------	------	222	60	235	256	151	305
		66.25	174	192	------	------	------	------	------	------	223	62	236	258	150	303
	+4	66.00	X173	191	------	------	------	------	------	------	224	64	237	259	148	301
		65.75	171	190	------	------	------	------	------	------	225	67	238	260	146	298
		65.50	170	189	------	------	------	------	------	------	226	68	238	261	144	297
	+.4	65.25	169	188	------	------	------	------	------	------	227	70	239	263	143	295
		65.00	168	187	------	------	------	------	------	------	228	72	240	X264	141	293
		64.75	167	186	------	------	------	------	------	------	229	74	241	266	X140	291

TABLE 9.—*Phenological seasons: Year-date constants for the beginning and ending of the seasons and their stages, with warm and cold period constants*—Continued

Zones		*Isop.*	Spring			Summer			Autumn			Warm	Winter			Cold
Ma	*Mi*		1	2	3	1	2	3	1	2	3	Per.	1	2	3	Per.
I		64.50	166	185	----	----	----	----	----	----	229	75	241	268	137	290
		64.25	165	184	----	----	----	----	----	----	230	77	242	269	135	288
		64.00	164	183	----	----	----	----	----	----	231	79	243	270	133	286
		63.75	163	182	----	----	----	----	----	----	232	81	244	272	131	284
		63.50	162	181	210	----	----	----	----	210	233	82	244	273	130	283
	.4	63.25	161	180	209	----	----	----	----	211	234	84	245	275	129	281
		63.00	160	179	208	----	----	----	----	212	X235	86	246	276	127	279
		62.75	159	178	207	----	----	----	----	213	236	88	247	277	125	277
		62.50	158	177	206	----	----	----	----	214	236	89	247	278	123	276
		62.25	157	176	205	----	----	----	----	215	237	91	248	280	121	274
		62.00	156	175	204	----	----	----	----	216	238	93	249	281	120	272
		61.75	155	174	203	----	----	----	----	217	239	95	250	282	119	270
	−.4	61.50	154	X173	X202	----	----	----	----	218	239	96	250	283	117	269
		61.25	153	171	200	----	----	----	----	219	240	98	251	285	115	267
		61.00	152	170	199	----	----	----	----	220	241	100	252	286	113	265
		60.75	151	169	198	----	----	----	----	221	242	102	253	287	X111	263
	−4	60.50	150	168	197	----	----	----	----	222	242	103	253	288	110	262
		60.25	149	167	196	----	----	----	----	223	243	105	254	290	108	260
		60.00	148	166	195	----	----	----	----	224	244	107	255	291	106	258
II	+1	59.75	147	165	194	----	----	----	----	225	245	109	256	292	105	256
		59.50	146	164	193	----	----	----	----	226	245	110	256	294	103	255
	+.1	59.25	145	163	192	----	----	----	----	227	246	112	257	295	102	253
		59.00	144	162	191	----	----	----	----	228	247	114	258	296	100	251
		58.75	143	161	190	----	----	----	----	229	248	116	259	297	98	249
		58.50	142	160	189	210	----	----	210	230	249	117	259	298	96	248
	.1	58.25	141	159	188	209	----	----	211	231	250	119	260	299	95	246
		58.00	X140	158	187	208	----	----	212	232	251	121	261	300	94	244
	−.1	57.75	138	157	186	207	----	----	213	233	252	124	262	301	93	241
		57.50	137	156	185	206	----	----	214	234	253	127	X264	302	92	238
	−1	57.25	136	155	184	205	----	----	215	X235	254	128	264	303	91	237
		57.00	135	154	183	204	----	----	216	236	255	130	265	304	90	235
		56.75	134	153	182	203	----	----	217	237	256	132	266	305	89	233
	+2	56.50	133	152	181	X202	----	----	218	238	257	134	267	306	88	231
		56.25	132	151	180	200	----	----	219	239	258	137	269	307	87	228
		56.00	131	150	179	199	----	----	220	240	259	139	270	308	86	226
		55.75	130	149	178	198	----	----	221	241	260	141	271	309	85	224
	+.2	55.50	129	148	177	197	----	----	221	242	261	143	272	310	84	222
		55.25	128	147	176	196	----	----	222	243	262	145	273	311	83	220
		55.00	127	146	175	195	----	----	223	244	X264	147	274	312	82	218
		54.75	126	145	174	194	----	----	224	245	264	149	275	313	81	216
		54.50	125	144	X173	193	----	----	225	246	265	150	275	314	80	215
		54.25	124	143	172	192	----	----	226	247	266	152	276	315	79	213
		54.00	123	142	171	191	----	----	227	248	267	154	277	316	78	211
	.2	53.75	122	141	170	190	----	----	228	249	268	156	278	317	77	209
		53.50	121	X140	169	189	----	----	229	250	269	158	279	318	76	207
		53.25	120	138	168	188	----	----	231	251	270	160	280	319	75	205
		53.00	119	137	167	187	----	----	232	252	271	162	281	320	74	203
		52.75	118	136	166	186	----	----	233	253	272	164	282	321	73	201
		52.50	117	135	165	185	----	----	234	254	273	166	283	322	72	199
	−.2	52.25	116	134	164	184	----	----	X235	255	274	168	284	323	71	197
		52.00	115	133	163	183	----	----	236	256	275	170	285	324	70	195
		51.75	114	132	162	182	----	----	237	257	276	172	286	325	69	193
	−2	51.50	113	131	161	181	----	----	238	258	277	174	287	326	68	191
		51.25	112	130	160	180	----	----	239	259	278	176	288	327	67	189
		51.00	X111	129	159	179	----	----	240	260	279	178	289	328	66	187
	+3	50.75	109	128	158	178	----	----	241	261	280	181	290	329	65	184
		50.50	108	127	157	177	----	----	241	262	281	183	291	330	64	182
	+.3	50.25	107	126	156	176	----	----	242	X264	282	185	292	331	63	180
		50.00	106	125	155	175	----	----	243	265	283	187	293	332	62	178
		49.75	105	124	154	174	----	----	244	266	284	189	294	333	61	176
	.3	49.50	104	123	153	X173	210	210	245	267	285	190	294	334	60	175
		49.25	103	122	152	172	209	211	246	268	286	192	295	335	59	173
		49.00	102	121	151	171	208	212	247	269	287	194	296	336	58	171
	−.3	48.75	101	120	150	170	207	213	248	270	288	196	297	337	57	169
		48.50	100	119	149	168	206	214	249	271	288	198	298	338	56	167
	−3	48.25	99	118	148	167	205	215	250	272	289	200	299	339	55	165
		48.00	98	117	147	166	204	216	251	273	290	202	300	340	54	163
		47.75	97	116	146	165	203	217	252	274	291	204	301	341	53	161
	+4	47.50	96	115	145	164	X202	218	253	274	292	206	302	342	52	159
		47.25	95	114	144	163	200	219	254	275	293	208	303	343	51	157
		47.00	94	113	143	162	199	220	255	276	294	210	304	344	50	155
	+.4	46.75	93	112	142	161	198	221	256	277	295	212	305	345	49	153
		46.50	92	X111	141	160	197	222	257	278	296	214	306	346	48	151
		46.25	91	109	X140	159	196	223	258	279	297	216	307	347	47	149
		46.00	90	108	138	158	195	224	259	280	298	218	308	348	46	147
		45.75	89	107	137	157	194	225	260	281	299	220	309	349	45	145
		45.50	88	106	136	156	193	226	261	282	300	222	310	350	44	143
	.4	45.25	87	105	135	155	192	227	263	283	301	224	311	351	43	141
		45.00	86	104	134	154	191	228	X264	284	302	226	312	352	42	139
		44.75	85	103	133	153	190	229	265	285	303	228	313	353	41	138
		44.50	84	102	132	152	189	230	266	286	304	230	314	354	40	135
		44.25	83	101	131	151	188	231	267	287	305	232	315	355	39	133
	−.4	44.00	82	100	130	150	187	232	268	288	306	234	316	356	38	131
		43.75	81	99	129	149	186	233	269	289	307	236	317	357	37	129
		43.50	80	97	127	147	185	X235	270	290	308	238	318	358	36	127
	−4	43.25	79	96	126	146	184	236	272	292	310	240	319	359	35	125
		43.00	78	95	125	145	183	238	273	293	311	242	320	360	34	123
	+5	42.75	77	94	124	144	182	239	274	294	312	244	321	361	33	121
		42.50	76	93	123	143	180	240	275	295	313	245	321	362	32	120
	+.5	42.25	75	92	122	142	179	242	276	297	314	247	322	363	31	118
		42.00	74	91	121	141	178	243	277	298	315	249	323	364	30	116
		41.75	73	90	120	X140	177	244	278	299	316	251	324	364	29	114
	.5	41.50	72	89	119	138	175	245	279	300	317	253	325	365	28	112
		41.25	71	87	118	137	174	246	280	301	319	255	326	1	27	110
		41.00	70	86	117	136	X173	247	281	302	320	257	327	X2	26	108
	−.5	40.75	69	85	116	135	171	248	282	303	321	259	328	3	25	106
		40.50	68	84	114	133	170	249	283	304	322	261	329	4	24	104
	−5	40.25	67	83	113	132	169	251	285	306	324	263	330	5	23	102
		40.00	66	82	112	131	168	252	286	307	325	265	331	6	22	100
		39.75	65	81	X111	128	165	254	287	308	326	267	332	7	21	98
	+6	39.50	64	79	108	126	162	257	289	309	327	269	333	8	20	96
		39.25	63	78	106	124	159	260	291	311	328	271	334	9	19	94
		39.00	62	77	104	122	156	X264	293	313	329	273	335	10	18	92

TABLE 9.—*Phenological seasons: Year-date constants for the beginning and ending of the seasons and their stages, with warm and cold period constants*—Continued

Zones		*Isop.*	Spring			Summer			Autumn			Warm	Winter			Cold
Ma	*Mi*		1	2	3	1	2	3	1	2	3	Per.	1	2	3	Per.
II		38.75	61	76	102	119	153	265	295	314	330	275	336	11	17	90
	+.6	38.50	60	74	100	117	150	267	297	315	331	277	337	12	16	88
		38.25	59	73	98	115	147	270	299	317	333	279	338	13	15	86
		38.00	58	72	96	112	144	273	301	319	334	281	339	14	14	84
		37.75	57	70	94	X111	X140	275	303	320	335	283	340	--------	--------	82
		37.50	56	68	92	107	136	278	305	321	336	285	341	--------	--------	80
		37.25	55	67	90	104	133	281	307	323	338	287	342	--------	--------	78
		37.00	54	66	88	102	130	284	309	325	339	289	343	--------	--------	76
	.6	36.75	53	65	86	99	127	286	310	326	340	291	344	--------	--------	74
		36.50	52	63	84	97	124	288	312	327	341	293	345	--------	--------	72
		36.25	51	62	82	95	121	291	314	329	342	295	346	--------	--------	70
		36.00	50	61	80	93	118	294	316	330	343	297	347	--------	--------	68
		35.75	49	60	78	90	114	296	318	331	344	299	348	--------	--------	66
	−.6	35.50	48	58	76	88	X111	298	320	332	345	301	349	--------	--------	64
		35.25	47	57	74	86	107	301	322	334	347	303	350	--------	--------	62
		35.00	46	56	72	84	104	304	324	336	348	305	351	--------	--------	60
		34.75	45	54	70	81	101	306	326	337	349	307	352	--------	--------	58
	−6	34.50	44	52	68	78	98	309	328	338	350	308	352	--------	--------	57
		34.25	43	51	66	76	95	312	330	340	352	310	353	--------	--------	55
		34.00	42	50	64	74	92	315	332	342	353	312	354	--------	--------	53
		33.75	41	49	62	71	89	317	333	343	354	314	355	--------	--------	51
	+7	33.50	40	47	60	69	86	319	335	344	355	316	356	--------	--------	49
		33.25	39	46	58	67	83	322	337	346	256	318	357	--------	--------	47
		33.00	38	45	57	65	80	325	339	348	357	320	358	--------	--------	45
	+.7	32.75	37	44	55	62	77	327	341	349	358	322	359	--------	--------	43
		32.50	36	42	53	60	74	330	343	350	359	324	360	--------	--------	41
		32.25	35	41	51	58	71	333	345	352	361	326	361	--------	--------	39
		32.00	34	40	50	56	68	336	347	354	363	328	362	--------	--------	37
	.7	31.75	33	38	48	53	64	338	348	355	--------	330	363	--------	--------	35
		31.50	32	36	46	50	61	340	350	356	--------	332	364	--------	--------	33
		31.25	31	35	44	48	58	343	352	358	--------	334	365	--------	--------	31
	−.7	31.00	30	34	42	46	55	346	354	360	--------	336	1	--------	--------	29
		30.75	29	33	40	43	51	348	356	361	--------	338	X2	--------	--------	27
		30.50	28	31	38	41	49	350	358	362	--------	339	2	--------	--------	26
	−7	30.25	27	30	36	39	46	353	360	364	--------	341	3	--------	--------	24
		30.00	26	29	34	37	43	356	362	1	--------	343	4	--------	--------	22
		29.75	25	28	32	34	40	358	363	2	--------	345	5	--------	--------	20
III	+1	29.50	24	26	30	32	37	360	365	X2	--------	347	6	--------	--------	18
		29.25	23	25	28	30	34	363	X2	5	--------	349	7	--------	--------	16
		29.00	22	24	26	28	31	365	4	6	--------	351	8	--------	--------	14
		28.75	21	22	24	25	27	X2	6	7	--------	353	9	--------	--------	12
	+.1	28.50	20	20	22	22	24	5	8	8	--------	354	9	--------	--------	11
		28.25	19	19	20	20	21	8	10	10	--------	356	10	--------	--------	9
		28.00	18	18	18	18	18	11	11	11	--------	358	11	--------	--------	7
		27.75	--------	--------	--------	17	--------	--------	12	--------	--------	360	12	--------	--------	5
	.1	27.50	--------	--------	--------	16	--------	--------	13	--------	--------	362	13	--------	--------	3
		27.25	--------	--------	--------	15	--------	--------	14	--------	--------	364	14	--------	--------	1
		27.00	--------	--------	--------	14	--------	--------	14	--------	--------	365	14	--------	--------	0

Schedule of modified unit constant rates in days for 1° isophanes

Spring			Summer			Autumn			Winter		
Stage	Isophanes	Rate	Stage	Isophanes	Rate	Stage	Isophanes	Rate	Stage	Isophanes	Rate
1	28.00–75.00	4.08+	1	27.00–40.00	9.00	1	58.50–44.50	4.00	1	75.00–58.50	2.96+
				40.00–44.50	4.66+		44.50–40.00	4.44+		58.50–27.00	3.80+
				44.50–58.50	4.14		40.00–27.00	7.15+			
2	28.00–40.00	5.33+	2	28.00–40.00	12.50	2	63.50–44.50	4.00	2	75.00–58.50	5.33+
	40.00–44.50	4.44+		40.00–44.50	4.66+		44.50–40.00	4.66+		58.50–38.00	3.95+
	44.50–70.50	4.13+		44.50–49.50	4.20		40.00–28.00	5.75			
3	28.00–40.00	7.83+	3	49.50–44.50	4.00	3	70.50–58.50	3.25	3	75.00–58.50	6.90+
	40.00–44.50	4.44+		44.50–40.00	4.88+		58.50–44.50	3.92+		58.50–38.00	4.00
	44.50–63.50	4.10+		40.00–28.00	10.33+		44.50–32.00	4.72			

EXPLANATION OF TABLE 9

The object of this table is to provide year-date constants for the beginning of the distinctive phenological seasons and of the second and third stages of each, with the number of days for the warm period of the year between the beginning of spring and the beginning of winter, and of the cold period between the beginning of winter and the beginning of spring for each 0.25° isophane from 75 to 27 of the Northern Hemisphere.

The standard unit constant rates by which the date constants of this table are computed are based on the rate of movement of the earth in its orbit of 360° in 365.25 days, and the corresponding rate of progress of the terrestrial seasons with the inclination of the earth's axis between the major season zone III of perpetual summer below isophane 27 and the major season zone I of perpetual winter above isophane 75.

The schedule gives the average rates per 1° for given ranges in isophanes for the seasons and the stages, which are applied in the usual way to the computation of date constants per 1° and 0.25° from the base records of equivalent isophane 44.50. This table applies specifically to season zone II of the *Northern Hemisphere* because the beginning of spring on January 18 on isophane 28 north is the date of midsummer south.

EXAMPLES OF APPLICATION

Part 1: Examples 6 and 7; figure 15.
Part 2: Examples 48, 49, 54, 71, 72, 73, 75, 76, 77, 84; figure 49.

TABLE 10.—*Altitude colimit constants for the major and minor zones*

Zones		Seal.	-I+II	II	Zones		Seal.	-I+II	II	II	II	II	II	II	-II+III
Ma	*Mi*	*Isop.*	-4+1	-1+2	*Ma*	*Mi*	*Isop.*	-4+1	-1+2	-2+3	-3+4	-4+5	-5+6	-6+7	-7+1
I		82.00	-8,800	---	I		66.75	-2,700	-3,900	---	---	---	---	---	---
		81.75	-8,700	---		-3	66.50	-2,600	-3,800	---	---	---	---	---	---
		81.50	-8,600	---		+4	66.25	-2,500	-3,700	---	---	---	---	---	---
		81.25	-8,500	---			66.00	-2,400	-3,600	---	---	---	---	---	---
		81.00	-8,400	-9,600			65.75	-2,300	-3,500	---	---	---	---	---	---
		80.75	-8,300	-9,500			65.50	-2,200	-3,400	---	---	---	---	---	---
		80.50	-8,200	-9,400			65.25	-2,100	-3,300	---	---	---	---	---	---
		80.25	-8,100	-9,300			65.00	-2,000	-3,200	---	---	---	---	---	---
		80.00	-8,000	-9,200			64.75	-1,900	-3,100	---	---	---	---	---	---
		79.75	-7,900	-9,100			64.50	-1,800	-3,000	---	---	---	---	---	---
		79.50	-7,800	-9,000			64.25	-1,700	-2,900	---	---	---	---	---	---
		79.25	-7,700	-8,900			64.00	-1,600	-2,800	---	---	---	---	---	---
		79.00	-7,600	-8,800			63.75	-1,500	-2,700	---	---	---	---	---	---
		78.75	-7,500	-8,700			63.50	-1,400	-2,600	---	---	---	---	---	---
		78.50	-7,400	-8,600			63.25	-1,300	-2,500	---	---	---	---	---	---
		78.25	-7,300	-8,500			63.00	-1,200	-2,400	---	---	---	---	---	---
		78.00	-7,200	-8,400			62.75	-1,100	-2,300	---	---	---	---	---	---
		77.75	-7,100	-8,300			62.50	-1,000	-2,200	---	---	---	---	---	---
		77.50	-7,000	-8,200			62.25	-900	-2,100	---	---	---	---	---	---
		77.25	-6,900	-8,100			62.00	-800	-2,000	---	---	---	---	---	---
		77.00	-6,800	-8,000			61.75	-700	-1,900	---	---	---	---	---	---
		76.75	-6,700	-7,900			61.50	-600	-1,800	---	---	---	---	---	---
		76.50	-6,600	-7,800			61.25	-500	-1,700	---	---	---	---	---	---
		76.25	-6,500	-7,700			61.00	-400	-1,600	---	---	---	---	---	---
		76.00	-6,400	-7,600			60.75	-300	-1,500	---	---	---	---	---	---
		75.75	-6,300	-7,500			60.50	-200	-1,400	---	---	---	---	---	---
		75.50	-6,200	-7,400			60.25	-100	-1,300	---	---	---	---	---	---
		75.25	-6,100	-7,300	-I	-4	60.00	0	-1,200	-3,600	-4,800	-6,800	-8,000	---	---
	-2	75.00	-6,000	-7,200	+II	+1	59.75	+100	-1,100	-3,500	-4,700	-6,700	-7,900	---	---
	+3	74.75	-5,900	-7,100			59.50	200	-1,000	-3,400	-4,600	-6,600	-7,800	---	---
		74.50	-5,800	-7,000			59.25	300	-900	-3,300	-4,500	-6,500	-7,700	---	---
		74.25	-5,700	-6,900			59.00	400	-800	-3,200	-4,400	-6,400	-7,600	---	---
		74.00	-5,600	-6,800			58.75	500	-700	-3,100	-4,300	-6,300	-7,500	---	---
		73.75	-5,500	-6,700			58.50	600	-600	-3,000	-4,200	-6,200	-7,400	---	---
		73.50	-5,400	-6,600			58.25	700	-500	-2,900	-4,100	-6,100	-7,300	---	---
		73.25	-5,300	-6,500			58.00	800	-400	-2,800	-4,000	-6,000	-7,200	-9,600	---
		73.00	-5,200	-6,400			57.75	900	-300	-2,700	-3,900	-5,900	-7,100	-9,500	---
		72.75	-5,100	-6,300			57.50	1,000	-200	-2,600	-3,800	-5,800	-7,000	-9,400	---
		72.50	-5,000	-6,200			57.25	1,100	-100	-2,500	-3,700	-5,700	-6,900	-9,300	---
		72.25	-4,900	-6,100		-1	57.00	1,200	0	-2,400	-3,600	-5,600	-6,800	-9,200	---
		72.00	-4,800	-6,000		+2	56.75	1,300	+100	-2,300	-3,500	-5,500	-6,700	-9,100	---
		71.75	-4,700	-5,900			56.50	1,400	200	-2,200	-3,400	-5,400	-6,600	-9,000	---
		71.50	-4,600	-5,800			56.25	1,500	300	-2,100	-3,300	-5,300	-6,500	-8,900	---
		71.25	-4,500	-5,700			56.00	1,600	400	-2,000	-3,200	-5,200	-6,400	-8,800	---
		71.00	-4,400	-5,600			55.75	1,700	500	-1,900	-3,100	-5,100	-6,300	-8,700	---
		70.75	-4,300	-5,500			55.50	1,800	600	-1,800	-3,000	-5,000	-6,200	-8,600	---
		70.50	-4,200	-5,400			55.25	1,900	700	-1,700	-2,900	-4,900	-6,100	-8,500	---
		70.25	-4,100	-5,300			55.00	2,000	800	-1,600	-2,800	-4,800	-6,000	-8,400	---
		70.00	-4,000	-5,200			54.75	2,100	900	-1,500	-2,700	-4,700	-5,900	-8,300	---
		69.75	-3,900	-5,100			54.50	2,200	1,000	-1,400	-2,600	-4,600	-5,800	-8,200	---
		69.50	-3,800	-5,000			54.25	2,300	1,100	-1,300	-2,500	-4,500	-5,700	-8,100	---
		69.25	-3,700	-4,900			54.00	2,400	1,200	-1,200	-2,400	-4,400	-5,600	-8,000	---
		69.00	-3,600	-4,800			53.75	2,500	1,300	-1,100	-2,300	-4,300	-5,500	-7,900	---
		68.75	-3,500	-4,700			53.50	2,600	1,400	-1,000	-2,200	-4,200	-5,400	-7,800	---
		68.50	-3,400	-4,600			53.25	2,700	1,500	-900	-2,100	-4,100	-5,300	-7,700	---
		68.25	-3,300	-4,500			53.00	2,800	1,600	-800	-2,000	-4,000	-5,200	-7,600	---
		68.00	-3,200	-4,400			52.75	2,900	1,700	-700	-1,900	-3,900	-5,100	-7,500	---
		67.75	-3,100	-4,300			52.50	3,000	1,800	-600	-1,800	-3,800	-5,000	-7,400	---
		67.50	-3,000	-4,200			52.25	3,100	1,900	-500	-1,700	-3,700	-4,900	-7,300	---
		67.25	-2,900	-4,100			52.00	3,200	2,000	-400	-1,600	-3,600	-4,800	-7,200	---
		67.00	-2,800	-4,000			51.75	3,300	2,100	-300	-1,500	-3,500	-4,700	-7,100	---

Zones		Seal.	-I+II	II	II	II	II	II	II	-II+III	III	III	III	III
Ma	*Mi*	*Isop.*	-4+1	-1+2	-2+3	-3+4	-4+5	-5+6	-6+7	-7+1	-1+2	-2+3	-3+4	-4
II		51.50	3,400	2,200	-200	-1,400	-3,400	-4,600	-7,000	-8,600	---	---	---	---
		51.25	3,500	2,300	-100	-1,300	-3,300	-4,500	-6,900	-8,500	---	---	---	---
	-2	51.00	3,600	2,400	0	-1,200	-3,200	-4,400	-6,800	-8,400	---	---	---	---
	+3	50.75	3,700	2,500	+100	-1,100	-3,100	-4,300	-6,700	-8,300	---	---	---	---
		50.50	3,800	2,600	200	-1,000	-3,000	-4,200	-6,600	-8,200	---	---	---	---
		50.25	3,900	2,700	300	-900	-2,900	-4,100	-6,500	-8,100	---	---	---	---
		50.00	4,000	2,800	400	-800	-2,800	-4,000	-6,400	-8,000	---	---	---	---
		49.75	4,100	2,900	500	-700	-2,700	-3,900	-6,300	-7,900	---	---	---	---
		49.50	4,200	3,000	600	-600	-2,600	-3,800	-6,200	-7,800	---	---	---	---
		49.25	4,300	3,100	700	-500	-2,500	-3,700	-6,100	-7,700	---	---	---	---
		49.00	4,400	3,200	800	-400	-2,400	-3,600	-6,000	-7,600	---	---	---	---
		48.75	4,500	3,300	900	-300	-2,300	-3,500	-5,900	-7,500	---	---	---	---
		48.50	4,600	3,400	1,000	-200	-2,200	-3,400	-5,800	-7,400	---	---	---	---
		48.25	4,700	3,500	1,100	-100	-2,100	-3,300	-5,700	-7,300	---	---	---	---
	-3	48.00	4,800	3,600	1,200	0	-2,000	-3,200	-5,600	-7,200	-9,600	---	---	---
	+4	47.75	4,900	3,700	1,300	+100	-1,900	-3,100	-5,500	-7,100	-9,500	---	---	---
		47.50	5,000	3,800	1,400	200	-1,800	-3,000	-5,400	-7,000	-9,400	---	---	---
		47.25	5,100	3,900	1,500	300	-1,700	-2,900	-5,300	-6,900	-9,300	---	---	---
		47.00	5,200	4,000	1,600	400	-1,600	-2,800	-5,200	-6,800	-9,200	---	---	---
		46.75	5,300	4,100	1,700	500	-1,500	-2,700	-5,100	-6,700	-9,100	---	---	---
		46.50	5,400	4,200	1,800	600	-1,400	-2,600	-5,000	-6,600	-9,000	---	---	---
		46.25	5,500	4,300	1,900	700	-1,300	-2,500	-4,900	-6,500	-8,900	---	---	---
		46.00	5,600	4,400	2,000	800	-1,200	-2,400	-4,800	-6,400	-8,800	---	---	---
		45.75	5,700	4,500	2,100	900	-1,100	-2,300	-4,700	-6,300	-8,700	---	---	---
		45.50	5,800	4,600	2,200	1,000	-1,000	-2,200	-4,600	-6,200	-8,600	---	---	---
		45.25	5,900	4,700	2,300	1,100	-900	-2,100	-4,500	-6,100	-8,500	---	---	---
		45.00	6,000	4,800	2,400	1,200	-800	-2,000	-4,400	-6,000	-8,400	---	---	---
		44.75	6,100	4,900	2,500	1,300	-700	-1,900	-4,300	-5,900	-8,300	---	---	---
		44.50	6,200	5,000	2,600	1,400	-600	-1,800	-4,200	-5,800	-8,200	---	---	---
		44.25	6,300	5,100	2,700	1,500	-500	-1,700	-4,100	-5,700	-8,100	---	---	---
		44.00	6,400	5,200	2,800	1,600	-400	-1,600	-4,000	-5,600	-8,000	---	---	---
		43.75	6,500	5,300	2,900	1,700	-300	-1,500	-3,900	-5,500	-7,900	---	---	---
		43.50	6,600	5,400	3,000	1,800	-200	-1,400	-3,800	-5,400	-7,800	---	---	---
		43.25	6,700	5,500	3,100	1,900	-100	-1,300	-3,700	-5,300	-7,700	---	---	---
	-4	43.00	6,800	5,600	3,200	2,000	0	-1,200	-3,600	-5,200	-7,600	---	---	---

TABLE 10.—*Altitude colimit constants for the major and minor zones*—Continued

Zones		Seal.	−I+II	II	II	II	II	II	II	−II+III	III	III	III	III
Ma	*Mi*	*Isop.*	−4+1	−1+2	−2+3	−3+4	−4+5	−5+6	−6+7	−7+1	−1+2	−2+3	−3+4	−4
II	+5	42.75	6,900	5,700	3,300	2,100	+100	−1,100	−3,500	−5,100	−7,500	---	---	---
		42.50	7,000	5,800	3,400	2,200	200	−1,000	−3,400	−5,000	−7,400	---	---	---
		42.25	7,100	5,900	3,500	2,300	300	−900	−3,300	−4,900	−7,300	---	---	---
		42.00	7,200	6,000	3,600	2,400	400	−800	−3,200	−4,800	−7,200	---	---	---
		41.75	7,300	6,100	3,700	2,500	500	−700	−3,100	−4,700	−7,100	---	---	---
		41.50	7,400	6,200	3,800	2,600	600	−600	−3,000	−4,600	−7,000	---	---	---
		41.25	7,500	6,300	3,900	2,700	700	−500	−2,900	−4,500	−6,900	---	---	---
		41.00	7,600	6,400	4,000	2,800	800	−400	−2,800	−4,400	−6,800	---	---	---
		40.75	7,700	6,500	4,100	2,900	900	−300	−2,700	−4,300	−6,700	---	---	---
		40.50	7,800	6,600	4,200	3,000	1,000	−200	−2,600	−4,200	−6,600	---	---	---
		40.25	7,900	6,700	4,300	3,100	1,100	−100	−2,500	−4,100	−6,500	---	---	---
	−5	40.00	8,000	6,800	4,400	3,200	1,200	0	−2,400	−4,000	−6,400	---	---	---
	+6	39.75	8,100	6,900	4,500	3,300	1,300	+100	−2,300	−3,900	−6,300	---	---	---
		39.50	8,200	7,000	4,600	3,400	1,400	200	−2,200	−3,800	−6,200	---	---	---
		39.25	8,300	7,100	4,700	3,500	1,500	300	−2,100	−3,700	−6,100	---	---	---
		39.00	8,400	7,200	4,800	3,600	1,600	400	−2,000	−3,600	−6,000	−9,600	---	---
		38.75	8,500	7,300	4,900	3,700	1,700	500	−1,900	−3,500	−5,900	−9,500	---	---
		38.50	8,600	7,400	5,000	3,800	1,800	600	−1,800	−3,400	−5,800	−9,400	---	---
		38.25	8,700	7,500	5,100	3,900	1,900	700	−1,700	−3,300	−5,700	−9,300	---	---
		38.00	8,800	7,600	5,200	4,000	2,000	800	−1,600	−3,200	−5,600	−9,200	---	---
		37.75	8,900	7,700	5,300	4,100	2,100	900	−1,500	−3,100	−5,500	−9,100	---	---
		37.50	9,000	7,800	5,400	4,200	2,200	1,000	−1,400	−3,000	−5,400	−9,000	---	---
		37.25	9,100	7,900	5,500	4,300	2,300	1,100	−1,300	−2,900	−5,300	−8,900	---	---
		37.00	9,200	8,000	5,600	4,400	2,400	1,200	−1,200	−2,800	−5,200	−8,800	---	---
		36.75	9,300	8,100	5,700	4,500	2,500	1,300	−1,100	−2,700	−5,100	−8,700	---	---
		36.50	9,400	8,200	5,800	4,600	2,600	1,400	−1,000	−2,600	−5,000	−8,600	---	---
		36.25	9,500	8,300	5,900	4,700	2,700	1,500	−900	−2,500	−4,900	−8,500	---	---
		36.00	9,600	8,400	6,000	4,800	2,800	1,600	−800	−2,400	−4,800	−8,400	---	---
		35.75	9,700	8,500	6,100	4,900	2,900	1,700	−700	−2,300	−4,700	−8,300	---	---
		35.50	9,800	8,600	6,200	5,000	3,000	1,800	−600	−2,200	−4,600	−8,200	---	---
		35.25	9,900	8,700	6,300	5,100	3,100	1,900	−500	−2,100	−4,500	−8,100	---	---
		35.00	10,000	8,800	6,400	5,200	3,200	2,000	−400	−2,000	−4,400	−8,000	---	---
		34.75	10,100	8,900	6,500	5,300	3,300	2,100	−300	−1,900	−4,300	−7,900	---	---
		34.50	10,200	9,000	6,600	5,400	3,400	2,200	−200	−1,800	−4,200	−7,800	---	---
		34.25	10,300	9,100	6,700	5,500	3,500	2,300	−100	−1,700	−4,100	−7,700	---	---
	−6	34.00	10,400	9,200	6,800	5,600	3,600	2,400	0	−1,600	−4,000	−7,600	---	---
	+7	33.75	10,500	9,300	6,900	5,700	3,700	2,500	+100	−1,500	−3,900	−7,500	---	---
		33.50	10,600	9,400	7,000	5,800	3,800	2,600	200	−1,400	−3,800	−7,400	---	---
		33.25	10,700	9,500	7,100	5,900	3,900	2,700	300	−1,300	−3,700	−7,300	---	---
		33.00	10,800	9,600	7,200	6,000	4,000	2,800	400	−1,200	−3,600	−7,200	---	---
		32.75	10,900	9,700	7,300	6,100	4,100	2,900	500	−1,100	−3,500	−7,100	---	---
		32.50	11,000	9,800	7,400	6,200	4,200	3,000	600	−1,000	−3,400	−7,000	---	---
		32.25	11,100	9,900	7,500	6,300	4,300	3,100	700	−900	−3,300	−6,900	---	---
		32.00	11,200	10,000	7,600	6,400	4,400	3,200	800	−800	−3,200	−6,800	---	---
		31.75	11,300	10,100	7,700	6,500	4,500	3,300	900	−700	−3,100	−6,700	---	---
		31.50	11,400	10,200	7,800	6,600	4,600	3,400	1,000	−600	−3,000	−6,600	---	---
		31.25	11,500	10,300	7,900	6,700	4,700	3,500	1,100	−500	−2,900	−6,500	---	---
		31.00	11,600	10,400	8,000	6,800	4,800	3,600	1,200	−400	−2,800	−6,400	---	---
		30.75	11,700	10,500	8,100	6,900	4,900	3,700	1,300	−300	−2,700	−6,300	---	---
		30.50	11,800	10,600	8,200	7,000	5,000	3,800	1,400	−200	−2,600	−6,200	---	---
		30.25	11,900	10,700	8,300	7,100	5,100	3,900	1,500	−100	−2,500	−6,100	---	---
−II	−7	30.00	12,000	10,800	8,400	7,200	5,200	4,000	1,600	0	−2,400	−6,000	---	---
+III	+1	29.75	12,100	10,900	8,500	7,300	5,300	4,100	1,700	+100	−2,300	−5,900	---	---
		29.50	12,200	11,000	8,600	7,400	5,400	4,200	1,800	200	−2,200	−5,800	---	---
		29.25	12,300	11,100	8,700	7,500	5,500	4,300	1,900	300	−2,100	−5,700	---	---
		29.00	12,400	11,200	8,800	7,600	5,600	4,400	2,000	400	−2,000	−5,600	−9,600	---
		28.75	12,500	11,300	8,900	7,700	5,700	4,500	2,100	500	−1,900	−5,500	−9,500	---
		28.50	12,600	11,400	9,000	7,800	5,800	4,600	2,200	600	−1,800	−5,400	−9,400	---
		28.25	12,700	11,500	9,100	7,900	5,900	4,700	2,300	700	−1,700	−5,300	−9,300	---
		28.00	12,800	11,600	9,200	8,000	6,000	4,800	2,400	800	−1,600	−5,200	−9,200	---
		27.75	12,900	11,700	9,300	8,100	6,100	4,900	2,500	900	−1,500	−5,100	−9,100	---
		27.50	13,000	11,800	9,400	8,200	6,200	5,000	2,600	1,000	−1,400	−5,000	−9,000	---
		27.25	13,100	11,900	9,500	8,300	6,300	5,100	2,700	1,100	−1,300	−4,900	−8,900	---
		27.00	13,200	12,000	9,600	8,400	6,400	5,200	2,800	1,200	−1,200	−4,800	−8,800	---
		26.75	13,300	12,100	9,700	8,500	6,500	5,300	2,900	1,300	−1,100	−4,700	−8,700	---
		26.50	13,400	12,200	9,800	8,600	6,600	5,400	3,000	1,400	−1,000	−4,600	−8,600	---
		26.25	13,500	12,300	9,900	8,700	6,700	5,500	3,100	1,500	−900	−4,500	−8,500	---
		26.00	13,600	12,400	10,000	8,800	6,800	5,600	3,200	1,600	−800	−4,400	−8,400	---
		25.75	13,700	12,500	10,100	8,900	6,900	5,700	3,300	1,700	−700	−4,300	−8,300	---
		25.50	13,800	12,600	10,200	9,000	7,000	5,800	3,400	1,800	−600	−4,200	−8,200	---
		25.25	13,900	12,700	10,300	9,100	7,100	5,900	3,500	1,900	−500	−4,100	−8,100	---
		25.00	14,000	12,800	10,400	9,200	7,200	6,000	3,600	2,000	−400	−4,000	−8,000	---
		24.75	14,100	12,900	10,500	9,300	7,300	6,100	3,700	2,100	−300	−3,900	−7,900	---
		24.50	14,200	13,000	10,600	9,400	7,400	6,200	3,800	2,200	−200	−3,800	−7,800	---
		24.25	14,300	13,100	10,700	9,500	7,500	6,300	3,900	2,300	−100	−3,700	−7,700	---
	−1	24.00	14,400	13,200	10,800	9,600	7,600	6,400	4,000	2,400	0	−3,600	−7,600	---
	+2	23.75	14,500	13,300	10,900	9,700	7,700	6,500	4,100	2,500	+100	−3,500	−7,500	---
		23.50	14,600	13,400	11,000	9,800	7,800	6,600	4,200	2,600	200	−3,400	−7,400	---
		23.25	14,700	13,500	11,100	9,900	7,900	6,700	4,300	2,700	300	−3,300	−7,300	---
		23.00	14,800	13,600	11,200	10,000	8,000	6,800	4,400	2,800	400	−3,200	−7,200	---
		22.75	14,900	13,700	11,300	10,100	8,100	6,900	4,500	2,900	500	−3,100	−7,100	---
		22.50	15,000	13,800	11,400	10,200	8,200	7,000	4,600	3,000	600	−3,000	−7,000	---
		22.25	15,100	13,900	11,500	10,300	8,300	7,100	4,700	3,100	700	−2,900	−6,900	---
		22.00	15,200	14,000	11,600	10,400	8,400	7,200	4,800	3,200	800	−2,800	−6,800	---
		21.75	15,300	14,100	11,700	10,500	8,500	7,300	4,900	3,300	900	−2,700	−6,700	−8,700
		21.50	15,400	14,200	11,800	10,600	8,600	7,400	5,000	3,400	1,000	−2,600	−6,600	−8,600
		21.25	15,500	14,300	11,900	10,700	8,700	7,500	5,100	3,500	1,100	−2,500	−6,500	−8,500
		21.00	15,600	14,400	12,000	10,800	8,800	7,600	5,200	3,600	1,200	−2,400	−6,400	−8,400
		20.75	15,700	14,500	12,100	10,900	8,900	7,700	5,300	3,700	1,300	−2,300	−6,300	−8,300
		20.50	15,800	14,600	12,200	11,000	9,000	7,800	5,400	3,800	1,400	−2,200	−6,200	−8,200
		20.25	15,900	14,700	12,300	11,100	9,100	7,900	5,500	3,900	1,500	−2,100	−6,100	−8,100
		20.00	16,000	14,800	12,400	11,200	9,200	8,000	5,600	4,000	1,600	−2,000	−6,000	−8,000
		19.75	16,100	14,900	12,500	11,300	9,300	8,100	5,700	4,100	1,700	−1,900	−5,900	−7,900
		19.50	16,200	15,000	12,600	11,400	9,400	8,200	5,800	4,200	1,800	−1,800	−5,800	−7,800
		19.25	16,300	15,100	12,700	11,500	9,500	8,300	5,900	4,300	1,900	−1,700	−5,700	−7,700
		19.00	16,400	15,200	12,800	11,600	9,600	8,400	6,000	4,400	2,000	−1,600	−5,600	−7,600
		18.75	16,500	15,300	12,900	11,700	9,700	8,500	6,100	4,500	2,100	−1,500	−5,500	−7,500
		18.50	16,600	15,400	13,000	11,800	9,800	8,600	6,200	4,600	2,200	−1,400	−5,400	−7,400
		18.25	16,700	15,500	13,100	11,900	9,900	8,700	6,300	4,700	2,300	−1,300	−5,300	−7,300
		18.00	16,800	15,600	13,200	12,000	10,000	8,800	6,400	4,800	2,400	−1,200	−5,200	−7,200
		17.75	16,900	15,700	13,300	12,100	10,100	8,900	6,500	4,900	2,500	−1,100	−5,100	−7,100
		17.50	17,000	15,800	13,400	12,200	10,200	9,000	6,600	5,000	2,600	−1,000	−5,000	−7,000
		17.25	17,100	15,900	13,500	12,300	10,300	9,100	6,700	5,100	2,700	−900	−4,900	−6,900
		17.00	17,200	16,000	13,600	12,400	10,400	9,200	6,800	5,200	2,800	−800	−4,800	−6,800

TABLE 10.—*Altitude colimit constants for the major and minor zones*—Continued

Zones		Seal.	−I+II	II	II	II	II	II	II	−II+III	III	III	III	III
Ma	*Mi*	*Isop.*	−4+1	−1+2	−2+3	−3+4	−4+5	−5+6	−6+7	−7+1	−1+2	−2+3	−3+4	−4
III		16.75	17,300	16,100	13,700	12,500	10,500	9,300	6,900	5,300	2,900	−700	−4,700	−6,700
		16.50	17,400	16,200	13,800	12,600	10,600	9,400	7,000	5,400	3,000	−600	−4,600	−6,600
		16.25	17,500	16,300	13,900	12,700	10,700	9,500	7,100	5,500	3,100	−500	−4,500	−6,500
		16.00	17,600	16,400	14,000	12,800	10,800	9,600	7,200	5,600	3,200	−400	−4,400	−6,400
		15.75	17,700	16,500	14,100	12,900	10,900	9,700	7,300	5,700	3,300	−300	−4,300	−6,300
		15.50	17,800	16,600	14,200	13,000	11,000	9,800	7,400	5,800	3,400	−200	−4,200	−6,200
		15.25	17,900	16,700	14,300	13,100	11,100	9,900	7,500	5,900	3,500	−100	−4,100	−6,100
	−2	15.00	18,000	16,800	14,400	13,200	11,200	10,000	7,600	6,000	3,600	0	−4,000	−6,000
	+3	14.75	18,100	16,900	14,500	13,300	11,300	10,100	7,700	6,100	3,700	+100	−3,900	−5,900
		14.50	18,200	17,000	14,600	13,400	11,400	10,200	7,800	6,200	3,800	200	−3,800	−5,800
		14.25	18,300	17,100	14,700	13,500	11,500	10,300	7,900	6,300	3,900	300	−3,700	−5,700
		14.00	18,400	17,200	14,800	13,600	11,600	10,400	8,000	6,400	4,000	400	−3,600	−5,600
		13.75	18,500	17,300	14,900	13,700	11,700	10,500	8,100	6,500	4,100	500	−3,500	−5,500
		13.50	18,600	17,400	15,000	13,800	11,800	10,600	8,200	6,600	4,200	600	−3,400	−5,400
		13.25	18,700	17,500	15,100	13,900	11,900	10,700	8,300	6,700	4,300	700	−3,300	−5,300
		13.00	18,800	17,600	15,200	14,000	12,000	10,800	8,400	6,800	4,400	800	−3,200	−5,200
		12.75	18,900	17,700	15,300	14,100	12,100	10,900	8,500	6,900	4,500	900	−3,100	−5,100
		12.50	19,000	17,800	15,400	14,200	12,200	11,000	8,600	7,000	4,600	1,000	−3,000	−5,000
		12.25	19,100	17,900	15,500	14,300	12,300	11,100	8,700	7,100	4.700	1,100	−2,900	−4,900
		12.00	19,200	18,000	15,600	14,400	12,400	11,200	8,800	7,200	4,800	1,200	−2,800	−4,800
		11.75	19,300	18,100	15,700	14,500	12,500	11,300	8,900	7,300	4,900	1,300	−2,700	−4,700
		11.50	19,400	18,200	15,800	14,600	12,600	11,400	9,000	7,400	5,000	1,400	−2,600	−4,600
		11.25	19,500	18,300	15,900	14,700	12,700	11,500	9,100	7,500	5,100	1,500	−2,500	−4,500
		11.00	19,600	18,400	16,000	14,800	12,800	11,600	9,200	7,600	5,200	1,600	−2,400	−4,400
		10.75	19,700	18,500	16,100	14,900	12,900	11,700	9,300	7,700	5,300	1,700	−2,300	−4,300
		10.50	19,800	18,600	16,200	15,000	13,000	11,800	9,400	7,800	5,400	1,800	−2,200	−4,200
		10.25	19,900	18,700	16,300	15,100	13,100	11,900	9,500	7,900	5,500	1,900	−2,100	−4,100
		10.00	20,000	18,800	16,400	15,200	13,200	12,000	9,600	8,000	5,600	2,000	−2,000	−4,000
		9.75	20,100	18,900	16,500	15,300	13,300	12,100	9,700	8,100	5,700	2,100	−1,900	−3,900
		9.50	20,200	19,000	16,600	15,400	13,400	12,200	9,800	8,200	5,800	2,200	−1,800	−3,800
		9.25	20,300	19,100	16,700	15,500	13,500	12,300	9,900	8,300	5,900	2,300	−1,700	−3,700
		9.00	20,400	19,200	16,800	15,600	13,600	12,400	10,000	8,400	6,000	2,400	−1,600	−3,600
		8.75	20,500	19,300	16,900	15,700	13,700	12,500	10,100	8,500	6,100	2,500	−1,500	−3,500
		8.50	20,600	19,400	17,000	15,800	13,800	12,600	10,200	8,600	6,200	2,600	−1,400	−3,400
		8.25	20,700	19,500	17,100	15,900	13,900	12,700	10,300	8,700	6,300	2,700	−1,300	−3,300
		8.00	20,800	19,600	17,200	16,000	14,000	12,800	10,400	8,800	6,400	2,800	−1,200	−3,200
		7.75	20,900	19,700	17,300	16,100	14,100	12,900	10,500	8,900	6,500	2,900	−1,100	−3,100
		7.50	21,000	19,800	17,400	16,200	14,200	13,000	10,600	9,000	6,600	3,000	−1,000	−3,000
		7.25	21,100	19,900	17,500	16,300	14,300	13,100	10,700	9,100	6,700	3,100	−900	−2,900
		7.00	21,200	20,000	17,600	16,400	14,400	13,200	10,800	9,200	6,800	3,200	−800	−2,800
		6.75	21.300	20,100	17,700	16,500	14,500	13,300	10,900	9,300	6,900	3,360	−700	−2,700
		6.50	21,400	20,200	17,800	16,600	14,600	13,400	11,000	9,400	7,000	3,400	−600	−2,600
		6.25	21,500	20,300	17,900	16,700	14,700	13,500	11,100	9,500	7,100	3,500	−500	−2,500
		6.00	21,600	20,400	18,000	16,800	14,800	13,600	11,200	9,600	7,200	3,600	−400	−2,400
		5.75	21,700	20,500	18,100	16,900	14,900	13,700	11,300	9,700	7,300	3,700	−300	−2,300
		5.50	21,800	20,600	18,200	17,000	15,000	13,800	11,400	9,800	7,400	3,800	−200	−2,200
		5.25	21,900	20,700	18,300	17,100	15,100	13,900	11,500	9,900	7,500	3,900	−100	2,100
	−3	5.00	22,000	20,800	18,400	17,200	15,200	14,000	11,600	10,000	7,600	4,000	0	−2,000
	+4	4.75	22,100	20,900	18,500	17,300	15,300	14,100	11,700	10,100	7,700	4,100	+100	−1,900
		4.50	22,200	21,000	18,600	17,400	15,400	14,200	11,800	10,200	7,800	4,200	200	−1,800
		4.25	22,300	21,100	18,700	17,500	15,500	14.300	11,900	10,300	7,900	4,300	300	−1,700
		4.00	22,400	21,200	18,800	17,600	15,600	14,400	12,000	10,400	8,000	4,400	400	−1,600
		3.75	22,500	21,300	18,900	17,700	15,700	14,500	12,100	10,500	8,100	4,500	500	−1.500
		3.50	22,600	21,400	19,000	17,800	15,800	14,600	12,200	10,600	8,200	4,600	600	−1,400
		3.25	22,700	21,500	19,100	17,900	15,900	14,700	12,300	10,700	8,300	4,700	700	−1,300
		3.00	22,800	21,600	19,200	18,000	16,000	14,800	12,400	10,800	8,400	4,800	800	−1,200
		2.75	22,900	21,700	19,300	18,100	16,100	14,900	12,500	10,900	8,500	4,900	900	−1,100
		2.50	23,000	21,800	19,400	18,200	16,200	15,000	12,600	11,000	8,600	5,000	1,000	−1,000
		2.25	23,100	21,900	19,500	18,300	16,300	15,100	12,700	11,100	8,700	5,100	1,100	−900
		2.00	23,200	22,000	19,600	18,400	16,400	15,200	12,800	11,200	8,800	5,200	1,200	−800
		1.75	23,300	22,100	19,700	18,500	16,500	15,300	12,900	11,300	8,900	5,300	1,300	−700
		1.50	23,400	22,200	19,800	18,600	16,600	15,400	13,000	11,400	9,000	5,400	1,400	−600
		1.25	23,500	22,300	19,900	18,700	16,700	15,500	13,100	11,500	9,100	5,500	1,500	−500
		1.00	23,600	22,400	20,000	18,800	16,800	15,600	13,200	11,600	9,200	5,600	1,600	−400
		.75	23,700	22,500	20,100	18,900	16,900	15,700	13,300	11,700	9,300	5,700	1,700	−300
		.50	23,800	22,600	20,200	19,000	17,000	15,800	13,400	11,800	9,400	5,800	1,800	−200
		.25	23,900	22,700	23,300	19,100	17,100	15,900	13,500	11,900	9,500	5,900	1,900	−100
	−4	.00	24,000	22,800	20,400	19,200	17,200	16,000	13,600	12,000	9,600	6,000	2,000	0

EXPLANATION OF TABLE 10

The elements of this table are the *Ma Mi* vertical scale of major and minor zonal colimit constants for the vertical scale of sea-level isophanes from 82 poleward to the equatorial 0. The horizontal scale of major zonal colimit constants and the scale of minor zonal colimit constants on the upper lines are for the vertical columns of altitude constants for each colimit, minus below and plus above sea level, for each of the 1° and 0.25° sea-level isophanes. Thus by the sea-level isophanes the colimit constant of major zone lower −I and major zone upper +II and of their minor zones lower −4 and upper +1 are at sea level on isophane 60; −100 feet below sea level on isophane 60.25; −8,800 feet on isophane 82; +100 feet on isophane 59.75; 6,800 feet above sea level on isophane 43; and 24,000 feet above sea level on isophane 0. The colimit constant of major −II and +III is at sea level on isophane 30; −5,200 feet (i. e., below sea level) on isophane 43; −8,600 feet on isophane 51.50; 2,400 feet above sea level on isophane 24; and 12,000 feet above sea level on isophane 0.

The purpose of this table is to facilitate the finding of the zonal colimit constant for any isophane by the *pa* and the record or interpreted modified altitude for the colimit by the latitude (or altitude) variation index. The given altitudes above or below a given position isophane represent the altitudes of the *a*, *w*, and *c* colimit constants across the northern and southern continents, while any position isophane, as modified by the *lvx*, or any altitude, as modified by the equivalent *avx*, gives the modified altitude for the same colimit or zone as the constant for the *pi*. There are several methods of application, all of which are illustrated in the text.

EXAMPLES OF APPLICATION

Part 1: Examples 15, 16, 20, 22, 23, 24, 28, 28b; figures 24 and 25.

Part 2: Examples 60, 61, 62, 63, 64, 65, 67; figures 39, 41, 42.

Figure 55 (p. 184) gives data for table 10 in graphic form. To find a zonal constant refer the altitude of a given position to the scale of altitude constant; follow the altitude line until it intersects the position isophane which indicates the zonal constant for the position and the relative altitudes of the zonal colimit constants above and below it.

To find a record zone for a position, the *avx* plus or minus the position altitude gives the interpreted zone for the position, and the modified altitudes of the zonal colimits above and below it.

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TABLE 11.—*Altitude limit constants for winter wheat culture*

Zones		Isop.	.6	−5	−4	.4	+.3
Ma	*Mi*		*ll*	*lol*	*mo*	*hol*	*hl*
II		55.00	---------	---------	---------	---------	−2,000
		54.75	---------	---------	---------	---------	−1,900
		54.50	---------	---------	---------	---------	−1,800
		54.25	---------	---------	---------	---------	−1,700
		54.00	---------	---------	---------	---------	−1,600
		53.75	---------	---------	---------	---------	−1,500
		53.50	---------	---------	---------	---------	−1,400
		53.25	---------	---------	---------	---------	−1,300
		53.00	---------	---------	---------	---------	−1,200
		52.75	---------	---------	---------	---------	−1,100
		52.50	---------	---------	---------	---------	−1,000
		52.25	---------	---------	---------	---------	−900
		52.00	---------	---------	---------	---------	−800
		51.75	---------	---------	---------	---------	−700
		51.50	---------	---------	---------	---------	−600
		51.25	---------	---------	---------	---------	−500
		51.00	---------	---------	---------	−2,000	−490
		50.75	---------	---------	---------	−1,900	−300
		50.50	---------	---------	---------	−1,800	−200
		50.25	---------	---------	---------	−1,700	−100
	+.3	50.00	---------	---------	---------	−1,600	0
		49.75	---------	---------	---------	−1,500	+100
		49.50	---------	---------	---------	−1,400	200
		49.25	---------	---------	---------	−1,300	300
		49.00	---------	---------	---------	−1,200	400
		48.75	---------	---------	---------	−1,100	500
		48.50	---------	---------	---------	−1,000	600
		48.25	---------	---------	---------	−900	700
		48.00	---------	−3,200	−2,000	−800	800
		47.75	---------	−3,100	−1,900	−700	900
		47.50	---------	−3,000	−1,800	−600	1,000
		47.25	---------	−2,900	−1,700	−500	1,100
		47.00	---------	−2,800	−1,600	−400	1,200
		46.75	---------	−2,700	−1.500	−300	1,300
		46.50	---------	−2,600	−1,400	−200	1,400
		46.25	---------	−2,500	−1,300	−100	1,500
	.4	46.00	---------	−2,400	−1,200	0	1,600
		45.75	---------	−2,300	−1,100	+100	1,700
		45.50	---------	−2,200	−1,000	200	1,800
		45.25	---------	−2,100	−900	300	1 900
		45.00	---------	−2,000	−800	400	2,000
		44.75	---------	−1,900	−700	500	2,100
		44.50	---------	−1,800	−600	600	2,200
		44.25	---------	−1,700	−500	700	2,300
		44.00	---------	−1,600	−400	800	2,400
		43.75	---------	−1,500	−300	900	2,500
		43.50	---------	−1,400	−200	1,000	2,600
		43.25	---------	−1,300	−100	1,100	2,700
	−4	43.00	−2,800	−1,200	0	1,200	2,800
		42.75	−2,700	−1,100	+100	1,300	2,900
		42.50	−2,600	−1,000	200	1,400	3,000
		42.25	−2,500	−900	300	1,500	3,100
		42.00	−2,400	−800	400	1,600	3,200
		41.75	−2,300	−700	500	1,700	3,300
		41.50	−2,200	−600	600	1,800	3,400
		41.25	−2,100	−500	700	1.900	3,500
		41.00	−2,000	−400	800	2,000	3,600
		40.75	−1,900	−300	900	2,100	3,700
		40.50	−1,800	−200	1,000	2,200	3,800
		40.25	−1,700	−100	1,100	2,300	3,900
	−5	40.00	−1,600	0	1,200	2,400	4,000
		39.75	−1,500	+100	1,300	2,500	4,100
		39.50	−1,400	200	1,400	2,600	4,200
		39.25	−1,300	300	1,500	2,700	4,300
		39.00	−1,200	400	1.600	2,800	4,400
		38.75	−1,100	500	1,700	2,900	4,500
		38.50	−1,000	600	1,800	3,000	4,600
		38.25	−900	700	1,900	3,100	4,700
		38.00	−800	800	2,000	3.200	4,800
		37.75	−700	900	2,100	3.300	4,900
		37.50	−600	1,000	2,200	3,400	5,000
		37.25	−500	1,100	2,300	3,500	5,100
		37.00	−400	1.200	2,400	3 600	5,200
		36.75	−300	1,300	2,500	3,700	5,300
		36.50	−200	1,400	2,600	3.800	5,400
		36.25	−100	1.500	2,700	3,900	5,500
	6	36.00	0	1,600	2,800	4.000	5,600
		35.75	+100	1,700	2,900	4,100	5,700
		35.50	200	1,800	3,000	4,200	5,800
		35.25	300	1,900	3,100	4.300	5,900
		35.00	400	2,000	3,200	4.400	6,000
		34.75	500	2,100	3,300	4,500	6,100
		34.50	600	2,200	3,400	4,600	6,200

Zones		Isop.	.6	−5	−4	.4	+.3
Ma	*Mi*		*ll*	*lol*	*mo*	*hol*	*hl*
II		34.25	700	2.300	3,500	4,700	6,300
		34.00	800	2,400	3,600	4,800	6,400
		33.75	900	2,500	3 700	4,900	6,500
		33.50	1,000	2,600	3.800	5,000	6,600
		33.25	1,100	2,700	3,900	5,100	6,700
		33.00	1,200	2,800	4,000	5 200	6,800
		32.75	1,300	2,900	4,100	5,300	6,900
		32.50	1,400	3.000	4,200	5,400	7,000
		32.25	1,500	3,100	4,300	5,500	7,100
		32.00	1,600	3,200	4,400	5,600	7,200
		31.75	1,700	3,300	4,500	5,700	7,300
		31.50	1,800	3,400	4,600	5,800	7,400
		31.25	1,900	3,500	4,700	5,900	7,500
		31.00	2,000	3.600	4,800	6,000	7,600
		30.75	2,100	3.700	4.900	6,100	7,700
		30.50	2,200	3,800	5,000	6,200	7,800
		30.25	2,300	3,900	5,100	6,300	7,900
		30.00	2,400	4,000	5,200	6,400	8,000
III		29.75	2,500	4,100	5,300	6,500	8,100
		29.50	2,600	4,200	5,400	6,600	8,200
		29.25	2,700	4,300	5,500	6,700	8,300
		29.00	2,800	4,400	5,600	6,800	8,400
		28.75	2,900	4,500	5,700	6,900	8,500
		28.50	3,000	4,600	5,800	7,000	8,600
		28.25	3,100	4,700	5,900	7,100	8,700
		28.00	3,200	4,800	6,000	7,200	8,800
		27.75	3,300	4,900	6,100	7,300	8,900
		27.50	3.400	5,000	6,200	7,400	9,000
		27.25	3,500	5.100	6,300	7,500	9,100
		27.00	3,600	5,200	6,400	7.600	9,200
		26.75	3,700	5,300	6,500	7,700	9,300
		26.50	3,800	5,400	6,600	7,800	9.400
		26.25	3,900	5,500	6,700	7,900	9,500
		26.00	4,000	5,600	6,800	8.000	9,600
		25.75	4,100	5,700	6.900	8,100	9,700
		25.50	4,200	5,800	7.000	8,200	9,800
		25.25	4.300	5,900	7,100	8,300	9,900
		25.00	4,400	6,000	7,200	8,400	10,000
		24.75	4,500	6,100	7,300	8,500	10,100
		24.50	4,600	6,200	7,400	8,600	10,200
		24.25	4,700	6,300	7,500	8,700	10,300
		24.00	4,800	6.400	7,600	8,800	10,400
		23.75	4,900	6,500	7,700	8,900	10,500
		23.50	5,000	6,600	7,800	9,000	10,600
		23.25	5,100	6,700	7,900	9,100	10,700
		23.00	5,200	6,800	8,000	9,200	10,800
		22.75	5,300	6,900	8,100	9,300	10,900
		22.50	5,400	7,000	8,200	9,400	11,000
		22.25	5,500	7,100	8,300	9,500	11,100
		22.00	5,600	7,200	8,400	9,600	11,200
		21.75	5,700	7,300	8,500	9,700	11,300
		21.50	5,800	7,400	8,600	9,800	11,400
		21.25	5,900	7,500	8,700	9,900	11,500
		21.00	6,000	7,600	8,800	10,000	11,600
		20.75	6,100	7,700	8,900	10,100	11,700
		20.50	6,200	7,800	9,000	10,200	11,800
		20.25	6,300	7,900	9,100	10,300	11,900
		20.00	6,400	8,000	9,200	10,400	12,000
		19.75	6.500	8,100	9,300	10,500	12,100
		19.50	6,600	8,200	9,400	10,600	12,200
		19.25	6,700	8,300	9,500	10,700	12,300
		19.00	6,800	8,400	9,600	10,800	12,400
		18.75	6,900	8,500	9,700	10,900	12,500
		18.50	7,000	8,600	9,800	11,000	12,600
		18.25	7,100	8,700	9,900	11,100	12,700
		18.00	7,200	8,800	10,000	11,200	12,800
		17.75	7,300	8,900	10,100	11,300	12,900
		17.50	7,400	9,000	10,200	11,400	13,000
		17.25	7,500	9,100	10,300	11,500	13,100
		17.00	7,600	9,200	10,400	11,600	13,200
		16.75	7,700	9,300	10,500	11,700	13,300
		16.50	7,800	9,400	10,600	11,800	13,400
		16.25	7,900	9,500	10,700	11,900	13,500
		16.00	8,000	9,600	10,800	12,000	13,600
		15.75	8,100	9,700	10,900	12,100	13,700
		15.50	8,200	9,800	11,000	12,200	13,800
		15.25	8,300	9,900	11,100	12,300	13,900
		15.00	8.400	10,000	11,200	12,400	14,000
		14.75	8,500	10,100	11,300	12,500	14,100
		14.50	8,600	10,200	11,400	12,600	14,200
		14.25	8,700	10,300	11,500	12,700	14,300
		14.00	8,800	10,400	11,600	12,800	14,400

EXPLANATION OF TABLE 11

The purpose of this table is to supplement table 7 in giving the altitude limit constants for the limits of winter wheat culture within its isophane and altitude range on the northern and southern continents.

The elements of the table are the sea-level isophane scale from 55 poleward to 14 equatorward at intervals of 0.25°; the horizontal scale of minor zone indices in major II for each subject for the scale of limit subjects, as *ll* lowest limit, *lol* low optimum, *mo* mid-optimum, *hol* high optimum, and *hl* highest limit; and the corresponding vertical altitude limit constants for each subject. The principle and method of application of this table are the same as for table 10.

EXAMPLES OF APPLICATION

Part 1: Examples 13, 14, 21, 22, 23, 24, 28, 28b.

Table 12.—*Movements in days of time to distance in degrees: Calendar of year-date constants for (1) the revolution of the earth in its orbit, and (2) inclination of the earth's axis*

NORTH

Degrees		Time		Degrees		Time		Degrees		Time		Degrees		Time		Degrees		Time		Degrees		Time	
Lat.	Orb.	Month	*yd*	Lat.	Orb.	Month	*yd*	Lat.	Orb.	Month	*yd*	Lat.	Orb.	Month	*yd*	Lat.	Orb.	Month	*yd*	Lat.	Orb.	Month	*yd*
0	360		Ex. 79	30	30		110	60	60		141	90	90		St. 172	60	120		203	30	150		234
1	1		80	31	31		111	61	61		142	89	91		173	59	121		204	29	151		235
2	2		81	32	32		112	62	62		143	88	92		174	58	122		205	28	152		236
3	3		82	33	33		113	63	63		144	87	93		175	57	123		206	27	153		237
4	4		83	34	34		114	64	64		145	86	94		176	56	124		207	26	154		238
5	5	Mar	84	35	35	Apr	115	65	65	May	146	85	95	June	177	55	125	July	208	25	155	Aug	239
6	6		85	36	36		116	66	66		147	84	96		178	54	126		209	24	156		240
7	7		86	37	37		117	67	67		148	83	97		179	53	127		210	23	157		241
8	8		87	38	38		118	68	68		149	82	98		180	52	128		211	22	158		242
9	9		88	39	39		119	69	69		150	81	99		181	51	129		212	21	159		243
10	10		89	40	40		120	70	70		151	80	100		182	50	130		213	20	160		244
11	11		90	41	41		121	71	71		152	79	101		183	49	131		214	19	161		245
12	12		91	42	42		122	72	72		153	78	102		184	48	132		215	18	162		246
13	13		92	43	43		123	73	73		154	77	103		185	47	133		216	17	163		247
14	14		93	44	44		124	74	74		155	76	104		186	46	134		217	16	164		248
15	15		94	45	45		125	75	75		156	75	105		187	45	135		218	15	165		249
16	16		95	46	46		126	76	76		157	74	106		188	44	136		219	14	166		250
17	17		96	47	47		127	77	77		158	73	107		189	43	137		220	13	167		251
18	18		97	48	48		128	78	78		159	72	108		190	42	138		221	12	168		252
19	19		98	49	49		129	79	79		160	71	109		191	41	139		222	11	169		253
20	20	Apr	99	50	50	May	130	80	80	June	161	70	110	July	192	40	140	Aug	223	10	170	Sept	254
21	21		100	51	51		131	81	81		162	69	111		193	39	141		224	9	171		255
22	22		101	52	52		132	82	82		163	68	112		194	38	142		225	8	172		256
23	23		102	53	53		133	83	83		164	67	113		195	37	143		226	7	173		257
24	24		103	54	54		134	84	84		165	66	114		196	36	144		227	6	174		258
25	25		104	55	55		135	85	85		166	65	115		197	35	145		228	5	175		259
26	26		105	56	56		136	86	86		167	64	116		198	34	146		229	4	176		260
27	27		106	57	57		137	87	87		168	63	117		199	33	147		230	3	177		262
28	28		107	58	58		138	88	88		169	62	118		201	32	148		232	2	178		263
29	29		108	59	59		140	89	89		171	61	119		202	31	149		233	1	179		264

SOUTH

Lat.	Orb.	Month	*yd*	Lat.	Orb.	Month	*yd*	Lat.	Orb.	Month	*yd*	Lat.	Orb.	Month	*yd*	Lat.	Orb.	Month	*yd*	Lat.	Orb.	Month	*yd*
0	180		Ex. 265	30	210		295	60	240		325	90	270		St. 355	60	300		19	30	330		49
1	181		266	31	211		296	61	241		326	89	271		356	59	301		20	29	331		50
2	182		267	32	212		297	62	242		327	88	272		357	58	302		21	28	332		51
3	183		268	33	213		298	63	243		328	87	273		358	57	303		22	27	333		52
4	184	Sept	269	34	214	Oct	299	64	244		329	86	274		359	56	304		23	26	334		53
5	185		270	35	215		300	65	245	Nov	330	85	275	Dec	360	55	305		24	25	335	Feb	54
6	186		271	36	216		301	66	246		331	84	276		361	54	306	Jan	25	24	336		55
7	187		272	37	217		302	67	247		332	83	277		362	53	307		26	23	337		56
8	188		273	38	218		303	68	248		333	82	278		363	52	308		27	22	338		57
9	189		274	39	219		304	69	249		334	81	279		364	51	309		28	21	339		58
10	190		275	40	220		305	70	250		335	80	280		365	50	310		29	20	340		59
11	191		276	41	221		306	71	251		336	79	281		0	49	311		30	19	341		60
12	192		277	42	222		307	72	252		337	78	282		1	48	312		31	18	342		61
13	193		278	43	223		308	73	253		338	77	283		2	47	313		32	17	343		62
14	194		279	44	224		309	74	254		339	76	284		3	46	314		33	16	344		63
15	195		280	45	225		310	75	255		340	75	285		4	45	315		34	15	345		64
16	196		281	46	226		311	76	256		341	74	286		5	44	316		35	14	346		65
17	197		282	47	227		312	77	257		342	73	287		6	43	317		36	13	347		66
18	198		283	48	228		313	78	258		343	72	288		7	42	318		37	12	348		67
19	199	Oct	284	49	229	Nov	314	79	259		344	71	289		8	41	319		38	11	349		68
20	200		285	50	230		315	80	260	Dec	345	70	290	Jan	9	40	320		39	10	350		69
21	201		286	51	231		316	81	261		346	69	291		10	39	321	Feb	40	9	351	Mar	70
22	202		287	52	232		317	82	262		347	68	292		11	38	322		41	8	352		71
23	203		288	53	233		318	83	263		348	67	293		12	37	323		42	7	353		72
24	204		289	54	234		319	84	264		349	66	294		13	36	324		43	6	354		73
25	205		290	55	235		320	85	265		350	65	295		14	35	325		44	5	355		74
26	206		291	56	236		321	86	266		351	64	296		15	34	326		45	4	356		75
27	207		292	57	237		322	87	267		352	63	297		16	33	327		46	3	357		76
28	208		293	58	238		323	88	268		353	62	298		17	32	328		47	2	358		77
29	209		294	59	239		324	89	269		354	61	299		18	31	329		48	1	359		78
																				0	360		79

EXPLANATION OF TABLE 12

The purpose of this table is to supplement figure 28A of part 2 in providing year-date constants of the astronomic year for application in studies of progressive movements in time between the equinoxes and solstices with units of distance in the two major motions of the earth.

In the table *degrees* gives the corresponding degree of terrestrial latitude and celestial longitude for the movements beginning on the March equinox at the equator and orbital degree 360 and extending through the months and astronomic year to the March equinox in the same degree of the next calendar year.

Under *time* the year-date constants begin with the March equinox from midnight March 20, year-date 79 to midnight March 21, year-date 80, and progress through the months for the Northern Hemisphere to the September equinox from midnight September 21 to midnight September 22, through the months for the Southern Hemisphere to the end of the first calendar year on December 31 (year-date 365), and thence through the months of the first quarter of the next calendar and the last quarter of the astronomic year to the March equinox.

EXAMPLES OF APPLICATION

Part 2: Example 35; figures 28*A*, 28*B*, 30, 31, 32.

TABLE 13.—*Law of the astronomical seasons: Date and period constants for movements between the Tropical Circles*

Lat.	*a*	*a1*			*b*	*b1*			*b–a*	*tp*	*c*	*c1*			*c–b*	*a+b+c*
	p	Month	*md*	*yd*	*p*	Month	*md*	*yd*	*p*		*p*	Month	*md*	*yd*	*p*	*tp*
23.46 N.			21	172			21	172	0				21	172	365	365
23.00			19	170		June	23	174	4				19	170	361	365
22.00			15	166			27	178	12				15	166	353	365
21.00		June	11	162			1	182	20			June	11	162	345	365
20.00			7	158			4	185	27				7	158	338	365
19.00			3	154			8	189	35				3	154	330	365
18.00			30	150			12	193	43				30	150	322	365
17.00			26	146		July	16	197	51				26	146	314	365
16.00			23	143			21	202	59				23	143	306	365
15.00			18	138			25	206	68				18	138	297	365
14.00		May	14	134			28	209	75			May	14	134	290	365
13.00			10	130			1	213	83				10	130	282	365
12.00	93		6	126	93		5	217	91	186	93		6	126	274	365
11.00			3	123			9	221	98				3	123	267	365
10.00			29	119			13	225	106				29	119	259	365
9.00			25	115		August	16	228	113				25	115	252	365
8.00			21	111			22	234	123				21	111	242	365
7.00		April	16	106			24	236	130			April	16	106	235	365
6.00			12	102			30	242	140				12	102	225	365
5.00			9	99			3	246	147				9	99	218	365
4.00			5	95			6	249	154				5	95	211	365
3.00			1	91			10	253	162				1	91	203	365
2.00			28	87			14	257	170				28	87	195	365
1.00			24	83		September	19	262	179				24	83	186	365
.00			20	79			22	265	186				20	79	179	365
1.00 S.		March	17	76			26	269	193			March	17	76	172	365
2.00			13	72			30	273	201				13	72	164	365
3.00			8	67			4	277	210				8	67	155	365
4.00			5	64			8	281	217				5	64	148	365
5.00			1	60			11	284	224				1	60	141	365
6.00			25	56			15	288	232				25	56	133	365
7.00			21	52		October	19	292	240				21	52	125	365
8.00			18	49			23	296	247				18	49	118	365
9.00		February	14	45			27	300	255			February	14	45	110	365
10.00			10	41			30	303	262				10	41	103	365
11.00			6	37			3	307	270				6	37	95	365
12.00			2	33			7	311	278				2	33	87	365
13.00	89		30	30	90		11	315	285	179	89		30	30	80	365
14.00			26	26		November	15	319	293				26	26	72	365
15.00			21	21			19	323	302				21	21	63	365
16.00			18	18			23	327	309				18	18	56	365
17.00		January	14	14			27	331	317			January	14	14	48	365
18.00			10	10			1	335	325				10	10	40	365
19.00			6	6			4	338	332				6	6	33	365
20.00			3	3			8	342	339				3	3	26	365
21.00			31	365		December	12	346	346				31	365	19	365
22.00		December	27	361			16	350	354			December	27	361	11	365
23.00			23	357			20	354	362				23	357	3	365
23.46			21	355			21	355	365				21	355	0	365

EXPLANATION OF TABLE 13

This table gives the date and period constants for the movements of the astronomic seasons between the Tropical Circles with the inclination of the earth's axis during the periods (seasons) between the March and September equinoxes on the Equator and the June and December solstices on the Tropical Circles, to supplement figure 28B.

Lat. gives the latitude at intervals of 1° to 23.46° at the Tropical Circles north and south of the Equator; *ap*, *bp*, and *cp* give the periods in days between the equinoxes at the Equator and the solstices at the Tropical Circles; *a1*, *b1*, and *c1* give the months, *md* the month dates, and *yd* the year-dates in the progress of the movements between the Tropical Circles for each degree of latitude; *b–a p* gives the period in days between the *a1* and *b1* movements for each degree of latitude from 0 at the Tropic of Cancer to 186 days at the Equator and 365 days at the Tropic of Capricorn; *tp* gives the total period (186 days) for the two movements *a1* and *b1* north between the Equator and the Tropic of Cancer and (179 days) for the same movements between the Equator and the Tropic of Capricorn; *c—b p* gives the period in days for each degree of latitude between the dates of the *b1* and *c1* movements from 365 days at the Tropic of Cancer to 179 days at the Equator and 0 at the Tropic of Capricorn, while *a+b+c tp* gives the total period of 1 normal year of 365 days between the dates of the *a1* and *c1* movements, as *b—a p*+*c–b p* equals *a+b+c tp* for all latitudes. For leap year of the present 12-month calendar 1 day would be added from March 1 to December 31, inclusive, in this table, and from March 4 to December 31, inclusive, in table 14.

This table (1) represents day by day the principle of the astronomic law relative to the inclination of the earth's axis and the progressive movement of time between the equinoxes and solstices relative to the latitudes between the Tropical Circles; and (2) gives a basis for comparison of the astronomic movements in tropical latitudes of this table with the astro-terrestrial movements in latitudes of season zone II of the four seasons of table 16.

TABLE 14.—*Law of the astronomical seasons: Date and period constants for movements between the poles*

Lat.	a	a2			b	b2			b–a	tp	c	c2			c–b	a+b+c
	p	Month	md	yd	p	Month	md	yd	p		p	Month	md	yd	p	tp
90.00N			21	172			21	172	0				21	172	365	365
88.00			18	169		June	24	174	5				18	169	360	365
84.00			14	165			27	178	13				14	165	352	365
80.00		June	10	161			1	182	21			June	10	161	344	365
76.00			6	157			5	186	29				6	157	336	365
72.00			2	153			9	190	37				2	153	328	365
68.00			29	149			13	194	45				29	149	320	365
64.00			25	145		July	17	198	53				25	145	312	365
60.00			21	141			22	203	62				21	141	303	365
56.00		May	16	136			26	207	71			May	16	136	294	365
52.00			12	132			30	211	79				12	132	286	365
48.00	93		8	128			3	215	87				8	128	278	365
44.00			4	124	93		7	219	95	186	93		4	124	270	365
40.00			30	120			11	223	103				30	120	262	365
36.00			26	116		August	15	227	111				26	116	254	365
32.00			22	112			20	232	120				22	112	245	365
28.00		April	17	107			24	236	129			April	17	107	236	365
24.00			13	103			28	240	137				13	103	228	365
20.00			9	99			1	244	145				9	99	220	365
16.00			5	95			5	248	153				5	95	212	365
12.00			1	91			9	252	161				1	91	204	365
8.00			28	86			13	256	169				28	87	196	365
4.00			24	83		September	17	260	177				24	83	188	365
.00			20	79			22	265	186				20	79	179	365
4.00S		March	16	75			26	269	194			March	16	75	171	365
8.00			12	71			30	273	202				12	71	163	365
12.00			8	67			4	277	210				8	67	155	365
16.00			4	63			8	281	218				4	63	147	365
20.00			28	59			12	285	226				28	59	139	365
24.00			24	55		October	16	289	234				24	55	131	365
28.00			20	51			20	293	242				20	51	123	365
32.00		February	16	47			24	297	250			February	16	47	115	365
36.00			12	43			28	301	258				12	43	107	365
40.00			8	39			1	305	266				8	39	99	365
44.00			4	35			5	309	274				4	35	91	365
48.00	89		31	31	90		9	313	282	179	89		31	31	83	365
52.00			27	27		November	13	317	290				27	27	75	365
56.00			23	23			17	321	298				23	23	67	365
60.00		January	19	19			21	325	306			January	19	19	59	365
64.00			15	15			25	329	314				15	15	51	365
68.00			11	11			29	333	322				11	11	43	365
72.00			7	7			3	337	330				7	7	35	365
76.00			3	3			7	341	338				3	3	27	365
80.00			31	365		December	11	345	345				31	365	20	365
84.00		December	27	361			15	349	353			December	27	361	12	365
88.00			23	357			19	353	361				23	357	4	365
90.00			21	355			21	355	365				21	355	0	365

EXPLANATION OF TABLE 14

The principle, elements, and symbols of this table are in general the same as in table 13, although the latitudes are at intervals of 2° and 4°. The rates in days per degree of latitude are the same as in table 12 for latitude. Thus by dates the *a2* movement begins with the December 21 solstice at the South Pole and moves to the March 20 equinox at the Equator and on to the June 21 solstice at the North Pole, and then with the reverse inclination of the earth's axis the *b2* movement is from the June 21 solstice at the North Pole to the September 22 equinox at the Equator and on to December 21 of the next calendar year at the South Pole in 365+ days. In the same time by the same dates and periods there is a west-to-east orbital movement, as from the December solstice in all latitudes to the March equinox, June solstice, September equinox, and back to the December solstice.

TABLE 15.—*Law of day and night time: Sum constants in 12-hour units of day and night time for the astronomical season periods*

NORTH

AP	1		2		3		4		Year		
Md	Mar. 20–June 21		June 21–Sept. 22		Sept. 22–Dec. 21		Dec. 21–Mar. 20		Totals		Diff.
Latitude	*dt*	*nt*	*nt*	*dt*	*dt*	*nt*	*dt*	*nt*	*dt*	*nt*	*dt*
	a	*b*	*c*	*d*	*f*	*e*	*g*	*h*			
90	186	0	0	186	7	173	4	174	383	347	+36
89	185	1	1	185	8	172	5	173	383	347	36
88	183	3	3	183	9	171	7	171	382	348	34
87	182	4	4	182	10	170	8	170	382	348	34
86	181	5	5	181	11	169	9	169	382	348	34
85	180	6	6	180	12	168	10	168	382	348	34
84	178	8	8	178	14	166	12	166	382	348	34
83	177	9	9	177	15	165	13	165	382	348	34
82	175	11	11	175	17	163	15	163	382	348	34
81	174	12	12	174	18	162	16	162	382	348	34
80	172	14	14	172	19	161	18	160	381	349	32
79	170	16	16	170	21	159	20	158	381	349	32
78	168	18	18	168	23	157	22	156	381	349	32
77	167	19	19	167	25	155	24	154	383	347	36
76	165	21	21	165	27	153	26	152	383	347	36
75	163	23	23	163	29	151	28	150	383	347	36
74	161	25	25	161	31	149	30	148	383	347	36
73	159	27	27	159	33	147	32	146	383	347	36
72	157	29	29	157	36	144	35	143	385	345	40
71	155	31	31	155	38	142	37	141	385	345	40

TABLE 15.—*Law of day and night time: Sum constants in 12-hour units of day and night time for the astronomical season periods*—Contd.

NORTH—Continued

AP	1		2		3		4		Year		
Md	Mar. 20–June 21		June 21–Sept. 22		Sept. 22–Dec. 21		Dec. 21–Mar. 20		Totals		Diff.
	dt	*nt*	*nt*	*dt*	*dt*	*nt*	*dt*	*nt*			
Latitude	*a*	*b*	*c*	*d*	*f*	*e*	*g*	*h*	*dt*	*nt*	*dt*
70	152	34	34	152	41	139	40	138	385	345	40
69	150	36	36	150	44	136	43	135	387	343	44
68	147	39	38	148	47	133	46	132	388	342	46
67	144	42	41	145	51	129	49	129	389	341	48
66.46	143	43	42	144	52	128	51	127	390	340	50
65	138	48	47	139	55	125	54	124	386	344	42
64	134	52	50	136	58	122	56	122	384	346	38
63	131	55	53	133	60	120	58	120	382	348	34
62	129	57	56	130	61	119	60	118	380	350	30
61	127	59	58	128	62	118	61	117	378	352	26
60	125	61	60	126	64	116	63	115	378	352	26
59	123	63	62	124	65	115	64	114	376	354	22
58	122	64	63	123	66	114	65	113	376	354	22
57	121	65	65	121	68	112	66	112	376	354	22
56	120	66	66	120	69	111	67	111	376	354	22
55	119	67	67	119	69	111	67	111	374	356	18
54	118	68	68	118	70	110	68	110	374	356	18
53	117	69	69	117	71	109	69	109	374	356	18
52	116	70	70	116	71	109	70	108	373	357	16
51	115	71	71	115	72	108	71	107	373	357	16
50	114	72	72	114	73	107	72	106	373	357	16
48	113	73	73	113	74	106	73	105	373	357	16
46	112	74	74	112	75	105	74	104	373	357	16
45	111	75	75	111	76	104	75	103	373	357	16
44	111	75	75	111	76	104	75	103	373	357	16
43	110	76	76	110	77	103	76	102	373	357	16
42	110	76	76	110	77	103	76	102	373	357	16
40	109	77	77	109	78	102	77	101	373	357	16
39	108	78	78	108	79	101	78	100	373	357	16
38	107	79	79	107	79	101	78	100	371	359	12
37	106	80	80	106	80	100	79	99	371	359	12
34	105	81	81	105	81	99	80	98	371	359	12
32	104	82	82	104	81	99	80	98	369	361	8
30	103	83	83	103	82	98	81	97	369	361	8
27	102	84	84	102	83	97	82	96	369	361	8
23.46	101	85	85	101	84	96	83	95	369	361	8
21	100	86	86	100	85	95	84	94	369	361	8
18	99	87	87	99	86	94	85	93	369	361	8
15	98	88	88	98	87	93	86	92	369	361	8
12	97	89	89	97	88	92	87	91	369	361	8
8	96	90	90	96	89	91	88	90	369	361	8
5	95	91	91	95							
3					90	90	89	89	369	361	8
0	94	92	92	94	91	89	90	88	369	361	8
3S	93	93	93	93							
Total 12 hours	93	93	93	93	90	90	89	89			
Total 12 hours		186	372	186		180	358	178	730		
Total 24 hours		93	186	93		90	179	89	365		

SOUTH

Latitude	*a*	*b*	*c*	*d*	*f*	*e*	*g*	*h*	*dt*	*nt*	*dt*
3 N					90	90	89	89	369	361	+8
0	94	92	92	94	91	89	90	88	369	361	8
3 S	93	93	93	93							
5					92	88	91	87			
8	92	94	94	92	93	87	92	86	369	361	8
12	91	95	95	91	94	86	93	85	369	361	8
15	90	96	96	90	95	85	94	84	369	361	8
18	89	97	97	89	96	84	95	83	369	361	8
21	88	98	98	88	97	83	96	82	369	361	8
23.46	87	99	99	87	98	82	97	81	369	361	8
26	86	100	100	86	99	81	98	80	369	361	8
30	85	101	101	85	100	80	99	79	369	361	8
32	84	102	102	84	101	79	100	78	369	361	8
34	83	103	103	83	102	78	101	77	369	361	8
36	82	104	104	82	103	77	102	76	369	361	8
39	81	105	105	81	104	76	103	75	369	361	8
41	80	106	106	80	105	75	104	74	369	361	8
43	79	107	107	79	106	74	105	73	369	361	8

TABLE 15.—*Law of day and night time: Sum constants in 12-hour units of day and night time for the astronomical season periods*—Contd.

SOUTH—Continued

AP	1		2		3		4		Year		
Md	Mar. 20–June 21		June 21–Sept. 22		Sept. 22–Dec. 21		Dec. 21–Mar. 20		Totals		Diff.
Latitude	*dt*	*nt*	*nt*	*dt*	*dt*	*nt*	*dt*	*nt*	*dt*	*nt*	*dt*
	a	*b*	*c*	*d*	*f*	*e*	*g*	*h*			
45	78	108	108	78	107	73	106	72	369	361	8
47	77	109	109	77	108	72	107	71	369	361	8
48	76	110	110	76	109	71	108	70	369	361	8
50	75	111	111	75	110	70	109	69	369	361	8
51	74	112	112	74	111	69	110	68	369	361	8
52	73	113	113	73	112	68	111	67	369	361	8
53	72	114	114	72	113	67	112	66	369	361	8
54	71	115	114	72	114	66	113	65	370	360	10
55	71	115	115	71	115	65	114	64	371	359	12
56	70	116	116	70	116	64	115	63	371	359	12
57	69	117	117	69	117	63	116	62	371	359	12
58	68	118	118	68	118	62	117	61	371	359	12
59	67	119	119	67	120	60	118	60	372	358	14
60	66	120	121	65	121	59	120	58	372	358	14
61	64	122	122	64	123	57	122	56	373	357	16
62	63	123	123	63	126	54	124	54	376	354	22
63	61	125	125	61	128	52	126	52	376	354	22
64	59	127	126	60	131	49	129	49	379	351	28
65	57	129	129	57	134	46	132	46	380	350	30
66.46	53	133	133	53	137	43	137	41	380	350	30
67	51	135	136	50	138	42	138	40	377	353	24
68	48	138	141	45	140	40	140	38	373	357	16
69	44	142	145	41	142	38	143	35	370	360	10
70	41	145	149	37	144	36	145	33	367	363	4
71	38	148	152	34	146	34	148	30	366	364	2
72	36	150	155	31	148	32	150	28	365	365	0
73	34	152	158	28	150	30	152	26	364	366	−2
74	31	155	160	26	152	28	154	24	363	367	−4
75	29	157	162	24	154	26	156	22	363	367	−4
76	27	159	165	21	155	25	157	21	360	370	−10
77	25	161	167	19	157	23	159	19	360	370	−10
78	23	163	168	18	159	21	160	18	360	370	−10
79	21	165	170	16	161	19	162	16	360	370	−10
80	20	166	172	14	162	18	164	14	360	370	−10
81	18	168	174	12	164	16	166	12	360	370	−10
82	16	170	175	11	166	14	167	11	360	370	−10
83	14	172	176	10	168	12	168	10	360	370	−10
84	13	173	177	9	170	10	170	8	362	368	−6
85	12	174	178	8	171	9	172	6	363	367	−4
86	10	176	179	7	173	7	173	5	363	367	−4
87	9	177	180	6	174	6	174	4	363	367	−4
88	8	178	181	5	176	4	175	3	364	366	−2
89	7	179	182	4	178	2	176	2	365	365	0
90	6	180	183	3	180	0	178	0	367	363	+4
Total 12 hours	93	93	93	93	90	90	89	89			
Total 12 hours	186	372	186		180	358	178		730		
Total 24 hours	93	186	93		90	179	89		365		

EXPLANATION OF TABLE 15

The purpose of this table is to make the daytime and nighttime sum constants available for study and application in bioclimatics. *AP* in the upper space gives the numbers for the four seasons of the astronomic year; *Md* the months and dates of the equinoxes and solstices for each season by the standard 12-month calendar, and *dt* the daytime and *nt* nighttime columns of sums of 12-hour units for the given north and south latitudes. Under *year* is given the total 12-hour units of *dt* and *nt* in the 730 units for the year; and under *diff.* the units of day more (plus) or less (minus) than night for each of the given latitudes. In the lower space of the north and south sections of the table are given separately the total 12-hour units for *dt* and *nt*, the total 12-hour and 24-hour units for each season period, and also the 12- and 24-hour units for the two seasons between the dates of the equinoxes and for the year.

The latitude lines across the tables indicate the latitudes for which sums were furnished by the United States Naval Observatory, while the broken lines indicate the latitudes for which sums were determined from table 4 of the United States Coast and Geodetic Survey Bulletin, Serial No. 184, 1923. The sums for intervening latitudes and for 77° to 90° north and south were determined from computations or by the trend of the daytime and nighttime curves, fig. 29.

The sum constants of this table are applicable in many ways and to many bioclimatic problems in natural phenomena, e. g., (*a*) to determine the variation of the actual astronomic or recorded units of daytime or nighttime in days, hours, minutes, or seconds, from the given sum constant for any latitude in any year or period of years; (*b*) to determine the relations between the daytime sum constants for a given latitude and the period in a given astroterrestrial or terrestrial season; (*c*) to determine the relations between the length of daytime constants and any given seasonal phenomena at any place in a given latitude; and (*d*) to determine the relation of the sum or percentage of daytime to any bioclimatic, agricultural, or other problem involving a consideration of the subject.

EXAMPLES OF APPLICATION

Part 2: Examples 43, 44, 54, 71, 75; figure 29.

TABLE 16.—*Law of the astroterrestrial seasons: Date and period constants for the north and south zone of the four terrestrial seasons*

NORTH[1]

Latitude	1 spring			2 summer			3 autumn			Warm	4 winter		
	Month	d1 yd	P Days	Month	d2 yd	P Days	Month	d3 yd	P Days	P 1+2+3	Month	d4 yd	P Days
66.50		218	0		218	0		218	0	0		218	365
66.00	August	216	1		217	2		219	1	4		220	361
65.00		211	5	August	216	4		220	5	14		225	351
64.00		207	7		214	8		222	7	22	August	229	343
63.00		202	11		213	10		223	12	33		235	332
62.00	July	197	14		211	14		225	14	42		239	323
61.00		192	18		210	16		226	18	52		244	313
60.00		188	20		208	20		228	20	60		248	305
59.00		183	24		207	22		229	24	70		253	295
58.00		179	26		205	27	August	232	26	79	September	258	286
57.00		174	30		204	29		233	30	89		263	276
56.50		172	31		203	31		234	31	93		265	272
56.00	June	168	34		202	33		235	33	100		268	265
55.00		164	37		201	35		236	36	108		272	257
54.00		159	39		198	40		238	39	118		277	247
53.00		155	42	July	197	43		240	41	126		281	239
52.00		150	45		195	46		241	45	136		286	229
51.00		146	48		194	48		242	48	144	October	290	221
50.00		141	51		192	52		244	51	154		295	211
49.00	May	135	55		190	55		245	55	165		300	200
48.00		131	58		189	58		247	57	173		304	192
47.00		127	61		188	60		248	61	182		309	183
46.00		122	64		186	64		250	64	192		314	173
45.00		117	67		184	67		251	67	201	November	318	164
44.00		113	70		183	70		253	70	210		323	155
43.00	April	107	75		182	72	September	254	73	220		327	145
42.00		103	77		180	76		256	76	229		332	136
41.00		98	80		178	79		257	79	238		336	127
40.00		94	83		177	82		259	82	247		341	118
39.00		89	86	June	175	86		261	84	256		345	109
38.00		84	90		174	89		263	87	266	December	350	99
37.00		80	92		172	92		264	91	275		355	90
36.75	March	79	93		172	93		265	90	276		355	89
36.00		75	85		160	114		274	85	284		359	81
35.00		71	76	May	147	142	October	289	75	293		364	72
34.00		66	66		132	171		303	64	301		2	64
33.00		61	57	April	118	199	November	317	55	311		7	54
32.00		57	47		104	227		331	45	319		11	46
31.00		52	38		90	255	December	345	36	329	January	16	36
30.00	February	48	28	March	76	282		358	27	337		20	28
29.00		43	19		62	309	January	6	19	347		25	18
28.00		39	9	February	48	337		20	9	355		29	10
27.00		34	0		34	365		34	0	365		34	0

[1] Season zone II north.

SOUTH[2]

Latitude	3 spring			4 summer			1 autumn			Warm	2 winter		
	Month	d1 yd	P Days	Month	d2 yd	P Days	Month	d3 yd	P Days	P 3+4+1	Month	d4 yd	P Days
27.00		218	0	August	218	365	July	218	0	365	August	218	0
28.00		222	11		233	336		204	10	357		214	8
29.00		227	20	September	247	307		189	20	347		209	18
30.00	August	233	28		261	279	June	175	29	336		204	29
31.00		237	38		275	250		160	39	327	July	199	38
32.00		242	46	October	288	223	May	146	48	317		194	48
33.00		246	57		303	193		131	59	309		190	56
34.00		251	66	November	317	166		118	67	299		185	66
35.00		255	75		330	139	April	104	77	291		181	74
36.00	September	260	84		344	111		90	86	281		176	84
36.75		265	90		355	89		79	93	272		172	93
37.00		265	90		355	88		78	94	272	June	172	93
38.00		270	87		357	85		77	89	261		166	104
39.00		274	84	December	358	82		75	87	253		162	112
40.00		279	81		360	79		74	83	243		157	122
41.00		284	77		361	76		72	80	233		152	132
42.00	October	288	75		363	73	March	71	77	225		148	140
43.00		293	71		364	70		69	74	215		143	150
44.00		297	68		0	68		68	70	206	May	138	159
45.00		302	64		1	65		66	67	196		133	169
46.00		306	62		3	62		65	64	188		129	177
47.00		311	58		4	59		63	61	178		124	187
48.00		315	56		6	56		62	57	169		119	196
49.00	November	320	52		7	53		60	55	160		115	205
50.00		324	50		9	50		59	51	151		110	214
51.00		329	46		10	47		57	47	140	April	104	225
52.00		334	43		12	44		56	44	131		100	234
53.00		338	41		14	40		54	41	122		95	243
54.00		342	38		15	38		53	38	114		91	251
55.00		347	35	January	17	34		51	35	104		86	261
56.00	December	352	31		18	32		50	32	95		82	270
56.50		355	29		19	30		49	30	89		79	276
57.00		356	29		20	28		48	29	86	March	77	279
58.00		361	25		21	26	February	47	26	77		73	288
59.00		0	22		22	23		45	23	68		68	297
60.00		4	20		24	20		44	20	60		64	305
61.00	January	9	17		26	16		42	17	50		59	315
62.00		14	13		27	14		41	13	40		54	325
63.00		18	11		29	10		39	11	32		50	333
64.00		22	8		30	8		38	7	23	February	45	342
65.00		27	5		32	4		36	4	13		40	352
66.00	February	32	1	February	33	2		35	1	4		36	361
66.50		34	0		34	0		34	0	0		34	365

[2] Season zone II south.

EXPLANATION OF TABLE 16

The purpose of this table is to supplement figure 31 and is to be used in connection with table 9 in the comparison of the actual or record dates of the terrestrial seasons for a given latitude with the date constants to find the variation from the requirement constants of astroterrestrial law, which variation is utilized as an index to the dates of the beginning and the length of the seasons to be expected at any given geographic position or within a given region, as fully explained in part 2.

The principle of this table is similar to that of table 14 in that the date constants represent the movement of time by degrees of latitude with the inclination of the earth's axis but differs in that the movements are in accordance with astroterrestrial law and apply specifically to major season zone II, as limited by latitudes 27° and 66.50° north and south.

EXAMPLES OF APPLICATION

Part 2: Examples 38, 39, 40, 41, 42, 43, 44, 45, 81, 82; figures 30, 31, 32, 48.

GLOSSARY OF SYMBOLS

This glossary relates specifically to the symbols used in parts 1 and 2.

A or a

a, annual mean temperature (tables 2 and 3).
ac, altitude constant.
acw, transition climatic type between *wac* and *caw*.
ar, annual mean range.
Au (or *A*), autumn season or frost dates (tables 6 and 9).
avx, altitude variation index.
awc, transition climatic type between *wac* and *caw*.
Ax, area index.
ax, altitude index.
az, the *a* zone.

B or b

Bc or *bc*, base constant.
bi, base isophane.
bdif, base difference.
bm, base meridian.
bpll, base parallel.
Br or *br*, base record.
BZ, bioclimatic zone.

C or c

c, mean temperature of the coldest month (tables 2 and 3); also cold or cool topographic effect types.
caw, coastal or mountain climatic type with *c* warmer and *w* colder relative to *a*.
cp, constant period.
cr, cold thermal mean range.
CT or *ct*, climatic type, also coldest topographic effect type.
cwa, transition climatic type with *c* and *w* warmer than *a*.

D or d

d, mean maximum temperature of the year (table 4).
dif or *diff*, difference.
dt, daytime.
dv, day variation or variation in days.
dvx, day variation index.

E or e

E, earliest killing frost in autumn.
e, mean maximum temperature of the warmest month (table 4).
eba, equivalent base altitude.
ebi, equivalent base isophane.
EC or *ec*, equinoctial colure.
ed, equivalent days.
eft, equivalent in feet.
ei, equivalent isophane.
el, equivalent latitude.
env, enclosed valley topographic type.
es, effective sum.

F or f

f, highest recorded temperature (table 4).

G or g

g, lowest recorded temperature (record card A, part 1, and schedule 1).

H or h

H, harvest dates.
h, mean minimum temperature of the coldest month (table 4).
hl, high altitude limit.
hlc, high limit constant.
hnv, high narrow ravine topographic factor type.
hol, high optimum limit.
hra, high ravine topographic factor type.
hri, high ridge topographic factor type.
hsl, high slope topographic factor type.
hslr, high slope ravine topographic factor type.
hsu, high summit topographic factor type.
htr, high terrace topographic factor type.

I or i

i, mean minimum temperature of the year (table 4).
ic, isophane constant.
id, interpreted date.
iex, isophane equivalent index.
intc, intercontinental.
io, isophane position.
iv, isophane variation.
ix, isophane index.
IZ or *iz*, interpreted zone.

J or j

j, effective sum.
jp, effective sum period.

L or l

L, latest killing frost in spring.
lav, local altitude variation.
lbv, low broad valley topographic factor type.
lc, latitude constant.
ldv, local day variation.
le, latitude equivalent.
lev, latitude equivalent variation.
lex, latitude equivalent index.
lf, low flat topographic factor type.
li, latitude-isophane.
lir, latitude and isophane requirement (difference in degrees between *pl* and *pi*.
ll, low altitude or latitude limit.
llc, low limit constant.
lnv, low narrow valley topographic factor type.
lol, low optimum limit.
lr, requirement difference in latitude degrees between *el* and *ei*.
lra, low ravine topographic factor type.
lri, low ridge topographic factor type.
lsl, low slope topographic factor type
lslr, low slope ravine topographic factor type.
lsu, low summit topographic factor type.
ltr, lowland terrace topographic factor type.
lv, low valley topographic factor type; also latitude variation.
lvl, lowland valley topographic factor type.
lvx, latitude variation index.
lx, latitude index.

M or m

Ma or *ma*, major zone.
md, month date.
me, modified equivalent isophane (example card C, part 1).
mg, month or months of greatest precipitation.
Mi or *mi*, minor zone.
ml, month or months of least precipitation.
mo, midoptimum altitude or latitude.
moc, midoptimum constant.
mra, middle ravine topographic factor type.
mri, modified record isophane.
msl, middle slope topographic factor type.
msu, middle summit topographic factor type.
Mz or *mz*, minor zone.

N or n

N, north.
n, north; also normal topographic effect type.
nrc, nonrecord constant.
nrp, nonrecord position.
nt, nighttime.

P or p

P or *p*, period in days between dates.
pa, position altitude.
pac, position altitude constant.
par, position altitude record.

pc, position constant.
pd or *per*, period in days between dates.
pi, position isophane.
pic, position isophane constant.
pir, position isophane record.
pl, position latitude.
plo, position longitude.
pno, position number.
pr, position record.
pv, position variation or period variation.

Q or q

qc, quadrant constant.
qr, quadrant record.
Quad no, quadrant number.
qv, quadrant variation.

R or r

r, record.
ra, record altitude or range.
rd, record days or record date.
rdif, record difference.
rec, record.
rhl, record high limit.
ri, record isophane.
rl, record latitude.
rli, record latitude-isophane.
rll, record low limit.
rmo, record midoptimum.
rp, record position or record period.
Rx, regional index.
rz, record zone.
rzt, record zonal type.

S or s

S, seeding dates (table 7) or spring frost (table 6); also south.
s, south.
sb, sea-level base.
SC or *sc*, solstitial colure.
si, sea-level isophane.
sl, sea-level latitude.
Sp or *sp*, spring.
Su or *su*, summer.
sur, summit ridge topographic factor type.
SZ or *sz*, season zone.

T or t

t, annual precipitation.
tbi, timber-line base isophane.
tdt, total daytime.
tet, topographic effect type.
tft, topographic factor type.
tl, timber line.
tlc, timber-line constant.
tlr, timber-line record.
tlv, timber-line variation.
tr, terrace topographic factor type.
trp, thermal record period.
TZ or *tz*, thermal zone.

U or u

u, month of greatest precipitation.
usl, upper slope topographic factor type.

V or v

v, month of least precipitation; also variation of the variable from its constant.
va or *var*, variation of the variable from its constant.

W or w

w, mean temperature of the warmest month (tables 2 and 3); also warm topographic effect type.
wac, continental, interior, or Great Basin climatic type in which *w* is warmer and *c* colder relative to *a*.
Wi or *wi*, winter.
wr, warm thermal mean range.
wt, warmest topographic effect types.
WWP, winter wheat period.

Y or y

y, percent of sum of 12-hour units of daytime.
yd, year-date of the standard calendar.

Z or z

Z or *z*, zone.
ZC or *zc*, zonal constant.
zcl, zonal colimit.
zl, zonal limit.
zr, zonal record.
zt, zonal type.

Capital letters are also used for major groups of zonal types (part 2).

NUMERAL SYMBOLS

Roman numerals (I, II, III) are the major zones.
Arabic numerals are used (*a*) for the minor zones in the classification of the thermal, bioclimatic, or season zones (example 50, pt. 2) and (*b*) for minor groups of zonal types.

PLUS OR MINUS SYMBOLS

For sections of minor zones, + upper, +. upper middle; . middle, −. lower middle, and − lower.
For relative higher or lower record altitude positions of zones, + warmer than zonal constant by higher record temperature, earlier spring and later autumn dates, or longer period, giving a higher altitude position of zone or zonal type; − colder than zonal constant by lower record temperature, later spring and earlier autumn dates, or shorter period.

Schedule of relations and equivalents in the plus and minus symbols of record cards and variation charts

VARIATIONS IN LATITUDE DEGREES

On record card		On variation chart	
Sym.	Signification	Sym.	Signification
+ equals	+ higher and colder latitude than the equivalent isophane or latitude.	Equals −	Below the isophane.
+ equals	− colder and + later spring and summer and − earlier autumn and winter dates than the date constants for equivalent isophane.	Equals −	Do.
+ equals	− colder and − lower equivalent feet than the position altitude.	Equals −	Do.
− equals	− lower and warmer latitude than the equivalent isophane or latitude.	Equals +	Above the isophane.
− equals	+ warmer and − earlier dates for spring and summer, and + later dates for autumn and winter.	Equals +	Do.
− equals	+ warmer and higher equivalent feet than the position altitude.	Equals +	Do.

CONVERSION OF ONE COORDINATE INTO ANOTHER

+ equals	Latitude equivalent variation × 4 days, equals − colder variation (+) late spring (−) early autumn in days.	Equals −	Below the isophane.
+ equals	Latitude variation × 400 feet, equals − variation in feet.	Equals −	Do.
	+ variation in days × 100 feet equals − variation in feet.	Equals −	Do.
− equals	Latitude variation × 4 days, equals + warmer variations (−) early spring (+) late autumn in days.	Equals +	Above the isophane.
− equals	Latitude variation × 400 feet, equals + variation in feet.	Equals +	Do.
	− variation in days × 100 feet, equals + variation in feet.	Equals +	Do.

DEFINITIONS

Altitude.—Elevation of the land above the sea, sea level, or a given base level.
Area.—Minor land surface, small political division, farm, or field.
Astronomic (*Astronomical*).—Relative to the laws, principles, and systems of the science of astronomy.
Astronomic seasons.—Seasons defined by the dates of the equinoxes and solstices and unmodified by the inclination of the earth's axis.
Astronomic zone.—A continuous astronomic belt across a continent or around the world defined by parallels of latitude.
Astroterrestrial seasons.—Seasons modified in length by the inclination of the axis, but not by terrestrial or physiographic influences of land and water.
Base.—A geographic position, place, area, or region where consecutive records are kept on bioclimatic elements and from which constants are computed to represent the requirements of a natural law or principle, as intercontinental, continental,

regional, or local base. The word is also used as an adjective, as in base isophane, base latitude, base longitude, etc.

Bioclimatics.—A science of the relations between life and climate.

Bioclimatic zone.—A disconnected and irregular geographic area distinguished by a single element, e. g., temperature, or by a combination of bioclimatic elements. A zone is determined for a general region, area, or geographic position by its type or types.

Causation complex.—Combination of major and minor astronomic, terrestrial, continental, oceanic, regional, and local causes of observed effects, as revealed in the phenomena of life and climate of major and minor regions and specific places. No minor, regional, or local effect is assigned to a single major or minor cause, but to the *causation complex*, which includes the *modifying factors* (agencies which modify the effects of a primary cause), as major and minor physiographic and seasonal elements and the influence of man.

Causation-factor complex.—Combination of all causes and factors. A few effects may be assigned directly to a single factor, as the killing of vegetation by frost, but as a rule a local or immediate observed effect is due not to one factor but to many factors.

Chart.—A graphic expression of an element or combination of elements which serves to illustrate a law, principle, specific results, facts, or evidence.

Climate.—Average elements of weather. These are the effects of astronomic causes as modified, and controlled, by terrestrial causes. They represent a factor in the modification and control of biological effects.

Constant.—A determined or assumed unit of time, temperature, or distance to represent a normal or average requirement of a law or principle, relative to one or more geographic coordinates.

Coordinates.—Systems of unit constant rates and computed tables of constants in units of time, temperature, and distance, in which any one unit is equivalent to any other.

Crop seasons.—Seasonal periods in which crops develop from seeding to harvest.

Distance.—Degrees of latitude, isophane, or longitude, and feet or meters of elevation of the land above sea level.

Ecology.—The science of plant and animal associations and their progressive development.

Ecological types.—An association of plants (or plants and animals) within a local area or region, characterizing a distinctive minor bioclimatic zone.

Effect.—An observed characteristic response under the influence of major and minor causes and agencies. In bioclimatics all bioclimatic phenomena and elements are interpreted as effects of primary causes, and it is assumed that all minor effects are due to more than one cause.

Equivalent.—The relation of any one bioclimatic coordinate in time, temperature, or distance to any other of the same system of unit constants, as equivalent isophane or latitude in degrees to altitude or distance.

Factor.—Single or complex agency between minor causes and local effects.

Geographic (*Geographical*).—Relating to a unit, position, area, or region by isophane, latitude, longitude, and altitude; relating to distribution and zonation of life and climate.

Index.—Variation of the record variable from its constant, which indicates the zone, zonal type, element of climate, or season to be expected at a given position or within a given area.

Isophane.—A line on a map or chart to represent the requirements of bioclimatic law of equal phenomena. This line departs from a parallel of latitude at the rate of 1° for each 5° of longitude.

Intercontinental base.—A geographic position from which constants are computed for all continents.

Latitude.—Measure of distance in degrees north and south of the equator.

Law, natural (*or of nature*).—Any primary major or minor order and system of distinctive or recognizable *causes* or *effects* of natural phenomena. In bioclimatics two groups of natural laws are recognized, one of causes and the other of effects, instead of one group of laws of cause and effect.

Longitude.—A measure of distance in degrees east or west of a given (standard) meridian.

Meridians.—Lines on a map, globe, or chart, running from pole to pole at right angles to the Equator.

Modified.—Applied to any major cause or effect which is changed by a minor cause or factor. Astronomical causes *modify* the influence of terrestrial causes; terrestrial effects of astronomic and terrestrial causes are *modified* by continental, regional, and local causes and factors; and unit constant rates and constants are *modified* to meet certain requirements of higher altitude and latitude.

Nonrecord position.—A position without records, for which constants may be determined, or bioclimatic elements interpreted, by the *variation index* of the nearest record position or by the average of a number of record positions.

Nonrecord quadrant.—A quadrant for which no records are available and which is characterized by constants alone.

Optimum.—A position or region in which the physical bioclimatic type or type complex is especially favorable for a plant, animal, crop, type of farming, health, etc.

Parallels.—Lines on a map, globe, or chart, representing places of equal latitude and lines of equal phenomena under the requirements of astronomic law.

Period.—Length of time in hours, days, months, or years.

Phenology.—The science which treats of observed and recorded dates of seasonal phenomena of plants and animals and periods in days. These dates and periods serve as indices to the interpretation of the local type of seasons and zones.

Phenological index.—A date, period, variation, or equivalent in temperature or distance for a record position which serves to indicate the corresponding date, period, etc., for a nonrecord position.

Phenological seasons.—Seasons characterized by the average date of seasonal events and periods of plants and animals.

Pheno-meridian.—Lines on a map poleward and equatorward at approximately right angles to the isophanes and numbered to correspond with those of the meridians of longitude intersected by them on the forty-ninth parallel north. These represent lines of equal poleward and equatorward movements of seasonal phenomena under the requirements of bioclimatic law instead of along the meridians of longitude under the requirements of astronomic law.

Physiographic.—Refers especially to the physical features of a continent or local area as minor causes of modified effects of astronomic and terrestrial causes.

Physiographic complex.—Combination of physiographic causes.

Physiographic type.—A specific element or combination of elements of a region or local area by which the character of its effects is distinguished.

Position, geographic.—A record or nonrecord place, locality, region, or quadrant designated by the geographic coordinants (latitude, or isophane, longitude, and altitude), as position latitude, position altitude, position record, nonrecord position, position variation, position variation index, etc.

Quadrant.—A geographic area as defined by latitude (or isophane) and longitude in 1° more or less, or in some unit of distance.

Record.—A noted recorded or published fact or evidence, as observed or determined for any bioclimatic subject at a given place or geographic position, such as a date or period in days, temperature in degrees, date of occurrence of a seasonal or other event, timber line, etc.

Record quadrant.—A quadrant characterized by records of bioclimatic subjects or elements at one or more record positions.

Region.—A natural or arbitrarily designated major or minor area of a continent, characterized and distinguished by its geographic position and its conspicuous physiographic and bioclimatic elements, zones, seasons, types, etc.

Requirement.—An assumed unit or system of coordinate units of time, temperature, or distance adopted as an astronomic or bioclimatic constant to represent a law or principle, e. g., *requirement* latitude, isophane, or altitude constant.

Seasons.—Distinctive periods of the year as controlled by the revolution of the earth and inclination of its axis, either unmodified or modified by major and minor terrestrial influences.

Season zone.—A bioclimatic zone determined by the thermal index and by the dates and periods of seasonal events of plants and animals.

Snow line.—An approximate (or average) lower altitude or latitude limit of perpetual snow.

Terrestrial seasons.—Seasons modified in length and distribution by terrestrial or physiographic influences.

Thermal seasons.—Seasons determined by seasonal and annual ranges in temperature and the thermal index.

Thermal zone.—A bioclimatic zone characterized and distinguished by a standard range in the average annual mean temperature.

Timber line.—The upper limit by latitude or altitude of upright tree growth under favorable soil, climatic, and weather conditions.

Timber-line index.—Average sea-level or alpine timber line serving as a guide to the interpretation of the zones above and below it.

Time.—Progress of the day and year as controlled by the motions of the earth and as measured by the clock and by the standard calendar. In bioclimatics time is computed in days from any hour of one day or date to any hour of the next or any succeeding date, and not by *inclusive* dates. The year-date

is utilized in preference to the month date for records of observations and the measurement of periods.

Topography.—Regional or local land relief, elevation, exposure, drainage. Topography modifies the bioclimatic effects of major causes.

Type.—Divisions of the minor zones distinguished by characteristic bioclimatic, zonal, biologic, ecologic, topographic, climatic, thermal, seasonal, weather, agriculture, or economic, etc., elements.

Variable.—Any bioclimatic effect of a major or minor cause, causation complex, or factor complex capable of observation and record in units of time, temperature, or distance; or any observed element of nature expressible in numerical units or by name for which a corresponding constant or average under the requirements of a natural law or principle, or of any combination of laws and principles, can be conceived and defined for comparison with a corresponding constant. Thus any record of an effect of a cause or factor (or combination of causes and factors) is a variable.

Variation.—The difference between a given recorded or interpreted variable and its average or constant. The amount of difference is a measure of the relative intensity of the modifying influence.

Variation index.—A determined variation for a record position serving as a guide to the interpretation of a corresponding bioclimatic element, combination of elements, zone, or zonal type of a nonrecord position within the area represented by the record position.

Year-date.—The consecutive day of the calendar year beginning with January 1. This is the standard measure of time and is preferable to the month date principally because (1) it facilitates the computation of periods in observation days, and (2) it will apply to any system of the calendar beginning with January 1. (See schedule 4.)

Zone.—A major or minor area of the surface of the earth limited by latitude or altitude and characterized by specific bioclimatic, thermal, biologic, life, climatic, season, or other elements.

Zonal type.—Any distinctive bioclimatic element which serves to characterize a regional or local feature of modification within the limits of a given thermal *a* zone.

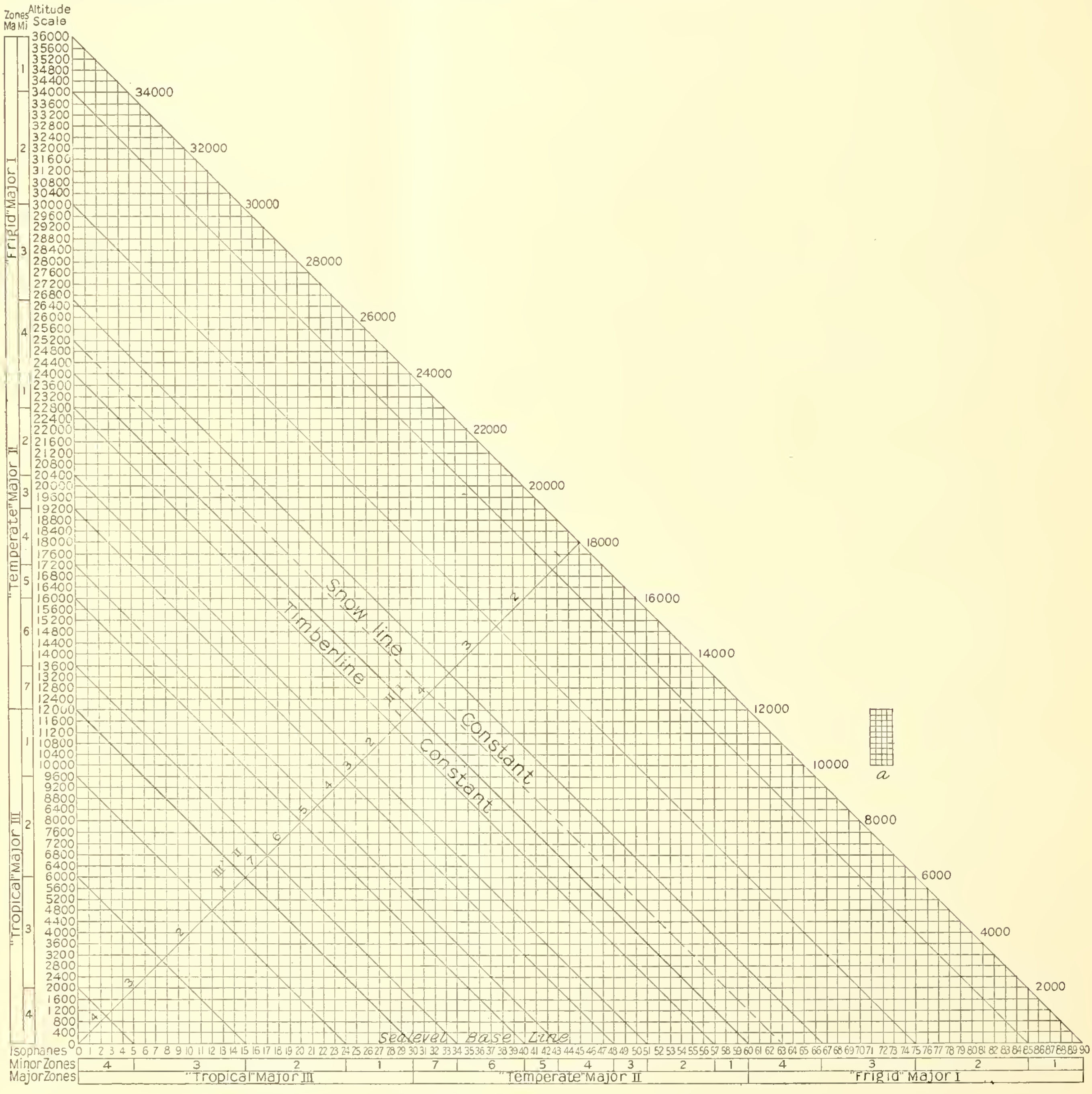

FIGURE 55.—Data for table 10 in graphic form.

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